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EDUCATION SERIES

ELEMENTS OF PRE-FLIGHT AERONAUTICS FOR HIGH SCHOOLS

BY THE
AVIATION EDUCATION
RESEARCH GROUP
Teachers College, University of Nebraska

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FRANK E. HENZLIK

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FOREWORD

The revolutionary influence of aviation on military strategy is now recognized by laymen as well as by military authorities. It is also apparent that the influences of aviation on civilian life are equally revolutionary and perhaps more important from the long-term viewpoint. Wide seas, dangerous reefs, precipitous mountains, frozen wastes, and jungle depths, all barriers to earthbound generations, have become features of the landscape below the global sweep of the airplane travelers in the ocean of air which is now the third dimension for an air-free people. No aspect of human ecology will remain unaltered by this new instrumentality which not only abolishes distances but also reshapes basic human geography and remolds the internal and external relationships of national and continental population groups. City, state, national, and even continental boundaries vanish or become curious anachronisms to the stratospheric travelers on great-circle routes which wheel around a planet bereft of topographical restrictions.

Our educational leaders and the schools and colleges which they represent have made it clear that they will not only contribute directly to the paramount task of winning the war by helping to train the young men who will give air supremacy to the United Nations but will also help prepare the American people for constructive living as world citizens in the air age. The War Department, the Navy Department, the Civil Aeronautics Administration, the United States Office of Education, and state and local educators are advocates of this type of education.

The AIR-AGE EDUCATION SERIES represents a major step in providing our schools with teaching materials for these purposes.

This series has two objectives. First, it seeks to provide text and teaching materials for older students in high schools in the field of pre-flight aeronautics. Second, it seeks to provide pertinent aviation materials which may be woven into existing courses in the curricula of the secondary schools and, wherever feasible, of the elementary schools.

To name all the men, women, schools, aviation industries and authorities, publishers, representatives of colleges, universities, school systems, non-profit institutions and agencies of State and Federal Governments who made possible the AIR-AGE EDUCATION SERIES would be a difficult task. In individual books, authors have acknowledged assistance and advice from many sources. Yet the series owes its existence more particularly to a few individuals and organizations.

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The Institute of the Aeronautical Sciences, a non-profit scientific society devoted to the advancement of aeronautics, is glad to sponsor the AIR-AGE EDUCATION SERIES in the belief that it will aid American education to eliminate the hiatus between technical aeronautical advances and popular understanding of aviation as a revolutionary world force today and tomorrow.

BEN D. WOOD
Chairman, Education Committee,
The Institute of the Aeronautical
Sciences

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UNIT I

LET'S FLY

Exploratory Activities

1. An automobile has a motor, gears, wheels, and a steering wheel, which make possible its operation. What do you know about the construction of an airplane which makes it possible for man to fly it through the air?
2. Have you ever flown in an airplane? Tell of your experience.
3. If you were to take a trip by airliner, where would you like to fly? Why?
4. Have you ever visited an airport? What did you see?
5. What do you know of the ways in which air travel is made safe?

Problem 1. How difficult is it to fly a plane?

"I want to learn to fly an airplane, a real plane." Thousands of you high-school people have made some such statement as this, either to yourselves or to your friends. Many of you have dreamed of flying since you were in the grades; you've been hanging around the local airport; you've been reading everything you could get your hands on about airplanes; you've been building model airplanes so late into the night that your parents have had to insist that you leave your building and go to bed so that you might be able to get up in time for school the next morning. Perhaps your sister or older brother has even remarked about you, "Bill's gone bats about airplanes."

Those of you who have shown such interest in planes and flying may already know something about the answer to the question, "How difficult is it to fly a plane?" But whether you've concluded that flying a plane is as easy as falling off a log or a pretty hard thing to do makes no difference to you. You are still going to fly, no matter what the obstacles are. Your interest is that great.

Then there are those of you to whom the idea of flying is a rather recent and sudden one; it has swooped down upon you like a dive bomber, and you are rather dubious about whether flying is for you. The sport of flying may appeal to you, and you probably see the advantages and opportunities that learning to fly can give you, but a very serious question continually confronts you: "Can I learn to fly? Just how difficult is it to fly?"

Physical fitness and flying. If you are physically fit and if you are willing to put some effort into the learning under the guidance of a good instructor, you can learn to fly the conventional airplane in such a way that flying will become as simple to you as driving an automobile.

Now all this isn't to say that, if you do not measure up to the foregoing qualifications, flying is out of the picture for you. If you are slow, it is not a sign that you cannot become a good pilot. It means simply that you will have to exercise a little more perseverance in training. If you have a tendency at the present time to be a bit cocky, reckless, and stubborn, you can with a little will power and sensible reasoning cultivate modesty, care, and open-mindedness; and you may be sure that, if your training instructor is a good one, he will do much to encourage desirable habits in you. He realizes that no two students are alike. You will be to him an individual with certain strong points and certain weaknesses. You will be a separate and distinct responsibility to him, and he will use the most appropriate method in training you to become a safe pilot. The important thing for you to do is to recognize any weak points you may have and then to go to work to do something about remedying them.

Before we fly. Certainly you are anxious to know just what flying a plane is like, particularly those of you who feel that some day you will be in the air piloting a plane, perhaps a plane of your very own. But before you climb into a plane with your instructor and take off into the blue for some imaginative flight instruction, let us pause to consider a few things about a plane which will give you an understanding of how simple a mechanism the plane is and why it flies.

The airplane has only three controls—the throttle, the stick, and the rudder pedals. The *throttle* is nothing more than the accelerator which feeds gas to the engine. It corresponds to the "footfeed" on an automobile. The *stick* might be said to correspond to the steering wheel of an automobile. As you sit in the cockpit you find the stick located between your knees. If you push it ahead, the plane noses in a downward direction; if you pull it back, the plane noses in an upward direction, or climbs. If you push the stick to the right, the plane "banks," or tilts, to the right; if you push it to the left, the plane banks to the left.

The *rudder pedals,* on which you place your feet, are, like the stick, steering devices. If you push the left pedal, the plane turns to the left; if you push the right, the plane turns to the right. Simple, isn't it? In flying you will use the pedals together with the stick to bank and turn the plane at the same time. If on your way home tonight you see a plane banking and turning gracefully, you will know what controls the pilot is operating.

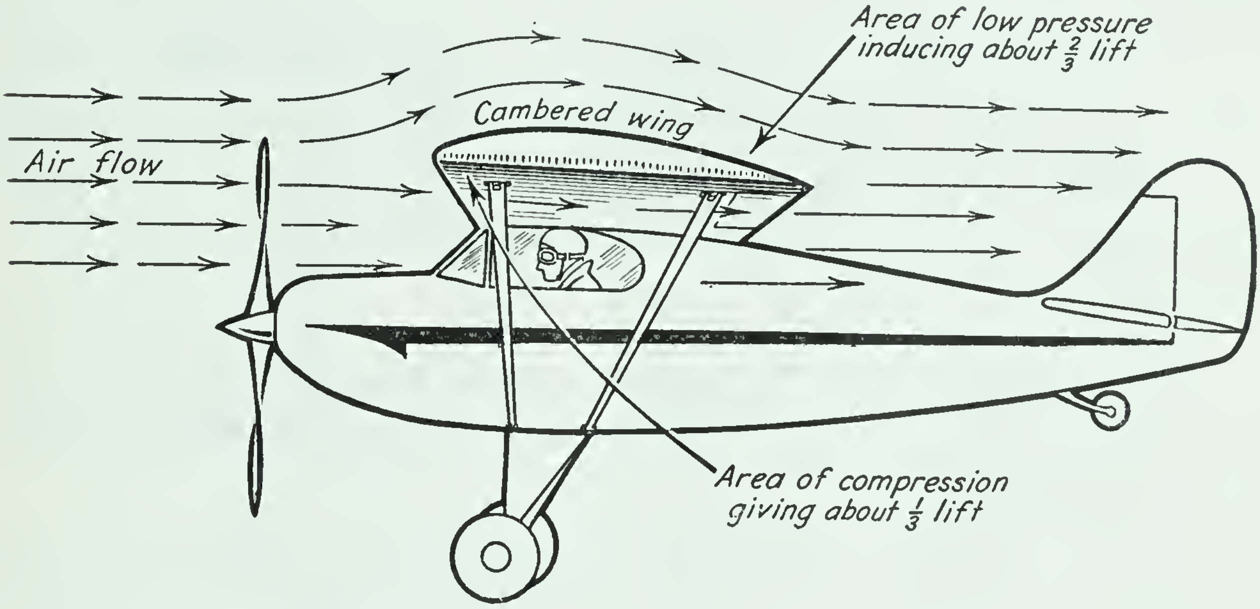

Area of low pressure inducing about $\frac{2}{3}$ lift
Cambered wing
Air flow
Area of compression giving about $\frac{1}{3}$ lift

Fig. 1. How the air stream acts upon the wings of a flying plane

How a plane flies. There is nothing mysterious about how a plane flies. That plane speeding along its invisible road in the sky may be breath-taking to you and fill you with wonderment and awe. The plane is, in truth, flying above your head, but the understanding of why it can so fly is not above your head. Have you ever, while riding in a car, extended your hand from the window and felt the lifting force under it when you held it flat and tilted only slightly toward the direction in which you were going? The conclusion you may draw here is an obvious one. Any flat-shaped object will have a tendency to rise or be lifted if it is forced speedily through the air at a slight angle of attack. You can better illustrate this with a shingle or a piece of cardboard held in your outstretched hand, its front, or leading edge, slightly raised. As the car drives along, the speed at which the shingle or cardboard strikes the air aimed glancingly at its under surface holds it aloft. So it is with an airplane. Speed provides a support for the airplane. The front, or leading edge, of a plane's wings in level flight is usually slightly raised. The propeller turned by the motor revolves at a tremendous speed and, because of its shape, literally screws into the air, thus exerting a pulling motion on the plane. This forward thrust of the plane's propeller is comparable to the forward thrust of a motorboat propeller. The pulling power of the propeller is one of the means that the pilot has to force the plane, with its flat-shaped wings, speedily through the air, thereby obtained lifting support.

It is well for you to understand at this point that speed does not contribute a lifting force merely at the bottom of a plane's wings. It affords a lifting force also, and twice as great a one, above the wings. It is known that air passing over a cambered, or convex, surface produces lift. So an airplane's wings are cambered on top. As the plane speeds forward the air passing over the cambered surface produces an area of low pressure and develops a lift to the surface of the wings.

Thus you see that an airplane speeding through the air is supported by the lift of its wings; speed makes a road for the plane. This road supports the plane just as surely as a paved highway supports an automobile.

So much for the controls and how an airplane flies. We have told you what the controls are and what they are for, and we have tried to explain to you that an airplane really has something to depend on for support—that when you are flying up above the world so high you are not riding on nothing, depending on magic to keep you aloft. On the contrary, you know you are being supported by air, *and air has substance and mass and the power to hold you up.* You will not be able to fly until you believe this, just as you cannot swim until you believe the water will carry you. You must come to trust the air.

How the controls act upon the plane. Let us walk over to the plane you are going to fly with your instructor and make some further examination of it. Now that you know what supports the plane and how it gets its life-giving speed, you need to know something about how the controls you operate in the cockpit make the plane fly level, turn, nose down, or climb. Here is the ship, a bright yellow training plane. It is, as you can see, of the high wing, monoplane type, powered by a 65-horsepower engine. Those hinged pieces which you see on the back, or trailing edge, of each wing near the tip are called *ailerons,* and they are both controlled by the stick, of which you already know something. The purpose of the ailerons is to enable you to lower or raise either the left or the right wing. Suppose, as you are flying the plane you notice the right wing is down, and you wish to lift it level again. The act is simple; you merely move the stick to the left, since that is the direction in which the plane will have to move in order to become level once more. As you push the stick to the left the aileron of the low wing hangs down on its hinges so that the wing extremity is "cupped." This gives the wing an added angle against which the airstream gives an extra upward force, thus raising the wing. The aileron on the left, or high, wing simultaneously swings upward so that the lifting force on this wing is decreased.

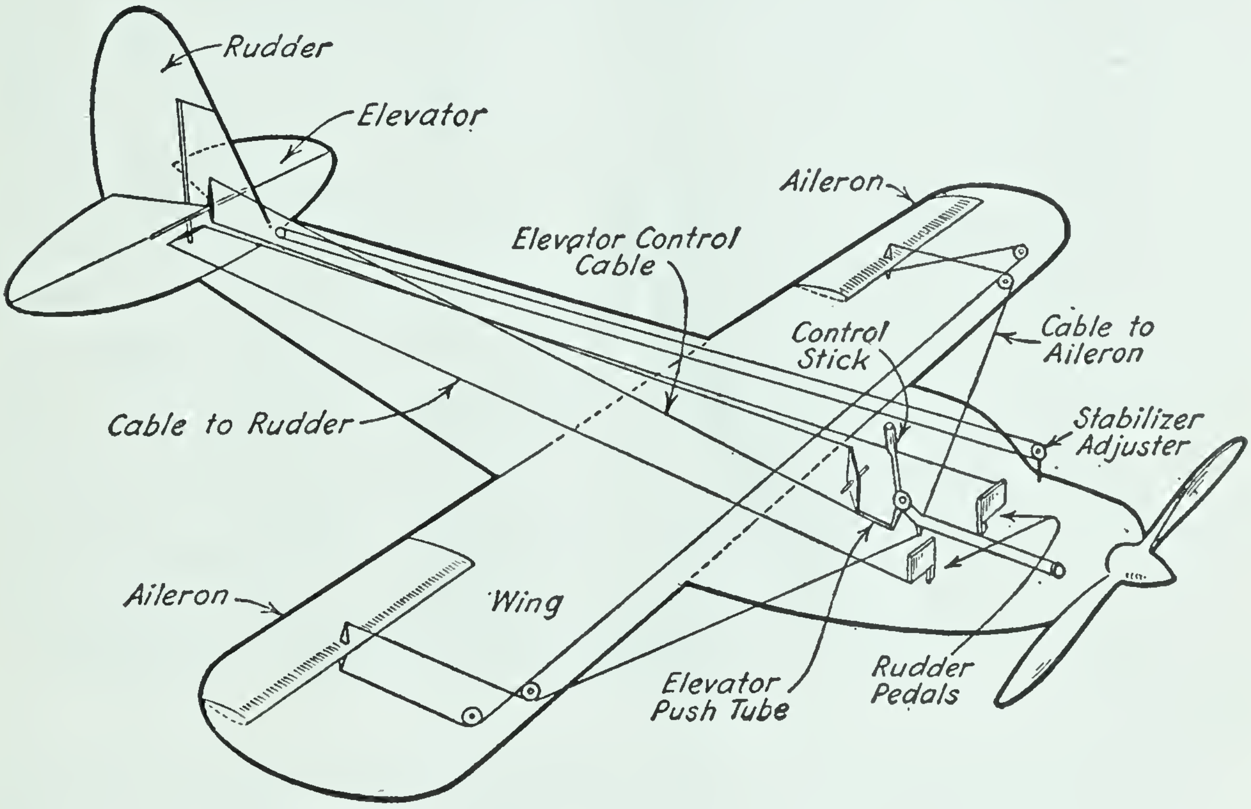


Fig. 2. Controls and control surfaces of a training plane

"But," you ask immediately, "when the aileron of the right wing is lowered, won't that cause the plane to turn to the right because of the added resistance to the air?" The question is a fair one. The plane will have a tendency to turn to the right, but you can keep it from doing so by means of another control. See this hinged vertical piece on the tail of the plane? It is known as the *rudder*. When operated from the cockpit by the rudder pedals, it causes the ship to turn left or right on a horizontal plane. Now as you are attempting to lift the right wing to a level position by moving the stick to the left, you can resist the movement of the plane to turn to the right by applying pressure to the left rudder pedal. In so doing you will be adjusting the rudder a sufficient amount to prevent the plane from turning to the right.

So it is that ailerons and rudder, though they operate separately, are used together in keeping the plane in a level position. But they are also used together in controlling the plane otherwise. Let us discuss this just a bit now to make flying a bit more meaningful to you when you go up in the air. Suppose as you sit at the controls of your speeding plane you wish to make a turn to the right. You push the right rudder. Of course, the nose of the ship will turn to the right, but in spite of that your plane will continue to go straight ahead instead of turning to the right as you wish it to. Why? Because you have not banked the ship. A plane needs a bank to negotiate a turn. Without the proper bank when attempting to turn, the airplane skids, much in the manner that an automobile skids when it is driven at a high rate of speed around a curve that is not banked. When a road is built highway curves are banked to accommodate highway traffic. But the bank in an airplane is made by the pilot. The amount of bank you make will depend on the degree of turn you wish to make. The sharper the turn the more bank you will need. Watch the birds bank sometime.

So in making turns you must operate both ailerons and rudder—both stick and pedals. To make the right turn properly you would proceed in this fashion: You would push gently on the right rudder, thus causing the nose of your plane to turn slowly to the right. At the same time you would push the stick slowly to the right, thus lowering the right wing, tilting, or banking, the plane and enabling it to turn. It is all very simple. To make a right turn: Right stick, right rudder. To make a left turn: Left stick, left rudder. It must be remembered, however, that stick and rudder are applied only until the desired rate of turn and the proper corresponding angle of bank are attained, after which they are neutralized. A stable plane will continue turning with a constant angle of bank until rudder and stick are reversed to bring the wings back to level position and stop the turn. Making a turn with an airplane is therefore unlike making a turn with an automobile, where the steering wheel is kept in turning position until the turn is made and then returned to a neutral position.

You have probably concluded already that in making turns successfully the proper combination of stick and rudder is necessary. That is right. And this proper combination you will gain soon with practice. It is a good idea to seat yourself in the cockpit of the plane while it is on the ground and get the feel and the range of the controls. Move the controls and try to visualize what the plane would be doing if it were flying.

Let us say a word now about another control surface on the tail. Notice these hinged horizontal pieces. They are called *elevators,* or "flippers," and the surface to which they are hinged is known as the *stabilizer.* When you push forward on the stick these flippers are drawn downward. The airstream striking on the lower surface of the elevators pushes the rear of the plane upward and so lowers the front, or nose. Pull backward on the stick and the elevators flip up. The air then strikes on the upper surfaces and pushes the tail of the plane downward. To the pilot's vision, then, the nose rises. Operating the stick to bring the nose of the plane up or down is easy to learn. The student naturally feels that, when he pushes forward on the stick, he is pushing downward on the nose, and that, when he pulls back on the stick, he is hauling the nose of the plane upward.

Instrument panel. Now we shall step over to the cockpit of this yellow machine and do one more thing—have a look at the instrument panel. Pilots need to have before them certain gauges, just as automobile drivers do. Here in front of you, as you sit with the stick between your knees, is the *turn-and-bank indicator.* When you are in the air and wish to make a turn this instrument guides you so that you do not overbank or underbank.

Here to the left of the turn-and-bank indicator is the *A.S.I.,* or *airspeed indicator,* which will show you how fast the air is flowing past your plane. Suppose you are flying against a wind that is blowing at 20 miles per hour and your airspeed indicator registers 110 miles per hour. This would mean to you that you were traveling at a speed of 90 miles per hour, or the air speed minus your head wind.

To show you the number of revolutions your engine is making you have here at the left of the airspeed indicator the *tachometer.* When you are cruising in this particular ship the engine revolutions should not exceed 2000 revolutions per minute. That is for the good of the plane's motor!

And now the *altimeter,* which shows you how high you are flying. Here it is at the right of the turn-and-bank indicator. In preparing to make cross-country flights pilots need to be very careful to study the map of their flight and to check the highest ground on the route they intend to fly. If there are hills on the way 1500 feet above sea level, pilots will have to be very careful to maintain a safe flying height. The altimeter is their means of checking.

The two remaining gauges are the *oil-pressure indicator* and the *oil-temperature indicator.* Every good pilot knows they need to be carefully watched, for the condition of oil in any motor is of vital importance.

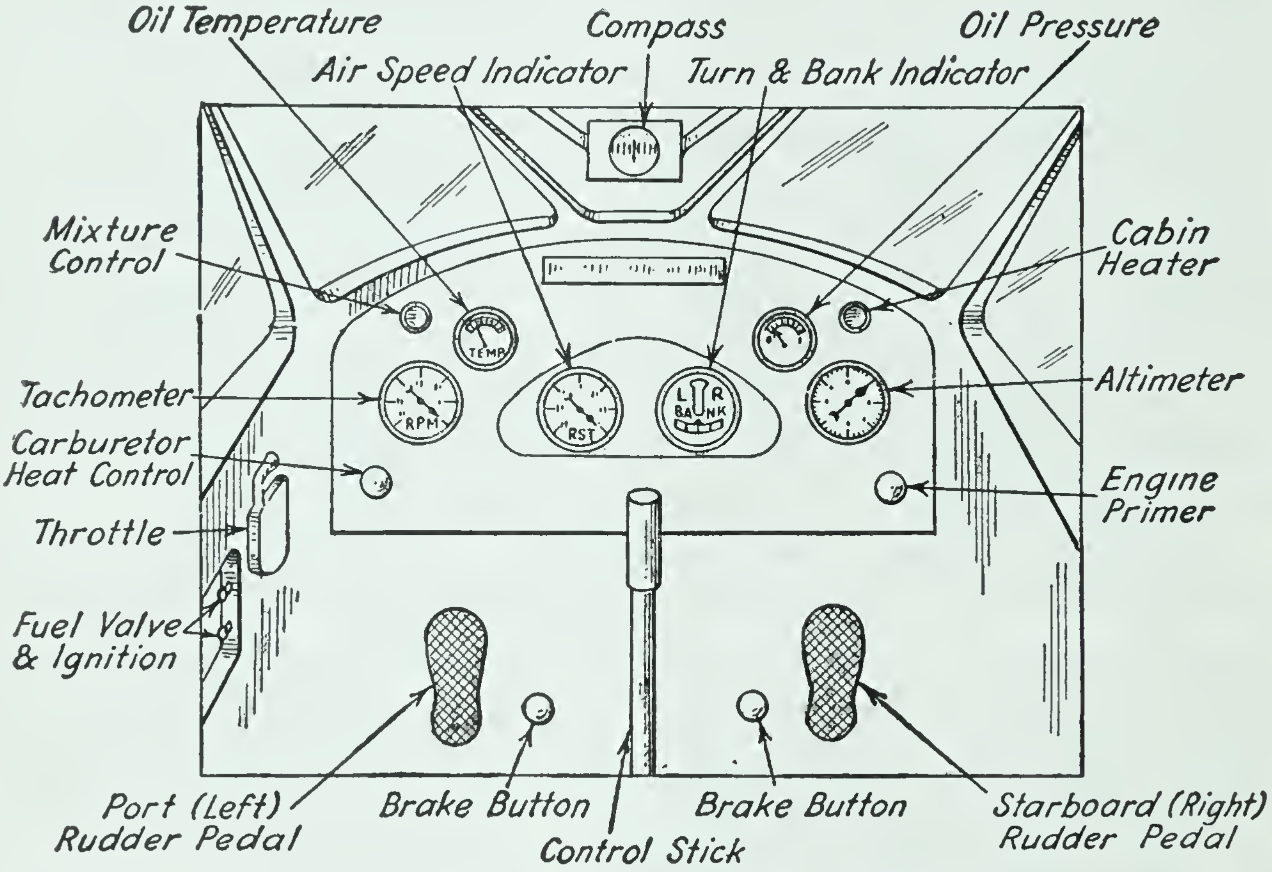


Fig. 3. Instrument panel and controls in the cockpits of a training plane

Enough now about controls and instruments at this time. You will learn much more about them as you proceed through this course in preflight aeronautics. But for the time being you know enough about them to appreciate a beginning lesson in flying a plane. Soon you are going to get a "taste of the stick."

A first lesson in flying. Today is the day you are to be given your first lesson in flying. The weather is warm and sunny, and it is almost wind-still. A few fluffy white clouds rest motionless against a background of pure blue sky. As you go through the airport gates and approach the hangar, before which several planes crouch with quiet propellers, you have a tightened feeling in the pit of your stomach—one which you cannot dispel with the deep breaths you force yourself to take. You turn your head to spot the cause of an ever-increasing roar, and there you see, banking gracefully over the outer reaches of the airport, a bright red plane, a plane made even redder by the contrast of its color against the blue background of the sky. You eye the plane and imagine yourself in the cockpit. "Boy," you think, "it won't be long until I'll be doing that." You don't know whether to be happy about it or turn tail and get out of the airport as fast as you can.

But you can't quit now. As you proceed doggedly to the hangar you recognize your flying instructor, with whom you have already made arrangements for flying lessons. He is a slim fellow wearing a rather worn flying jacket. His tight-fitting helmet and goggles give him a military appearance.

"Hello," he says, and smiles. He probably knows about that tight feeling you have in your stomach. "Are you all set?"

"All set," you answer. You reply and the note of bravery you managed to put into it give you unexpected courage.

"O.K. Let's go over to the ship we're going to fly and have a look at it," he replies, and he takes you over to a yellow plane, a high-wing monoplane, like the one we have described to you.

During the next half hour you find that your fears steal away. You are eagerly asking questions and listening interestedly as the instructor goes over the ship with you. He gives you much the same information about the plane and its controls as has already been presented here. He seats you in the cockpit and asks you to try the controls. He explains to you that the instructions you are receiving for this plane will enable you to pilot other ships easily later on. He assures you that when you are in the air handling the controls he will also have a set of controls to take over in case you need help or become confused.

Then suddenly the time for take-off comes. "I'm going to start the motor now," your instructor says, and directs you to take your seat in the plane where you may observe proper plane-starting procedures.

He assists you in fastening your safety belt, and then, after checking the wheels to be sure they are securely blocked, takes his place in the front seat of the plane. "This is correct starting procedure," he tells you. "Watch closely to see what I do." He turns on the gas and primes the engine, checks the switch to be certain it is off, and closes the throttle. The mechanic who has approached the plane to crank the engine calls: "Gas on—switch off—throttle closed." The instructor repeats: "Gas on—switch off—throttle closed." Now the mechanic calls, "Contact," and your instructor repeats, "Contact." Then he turns on the switch.

The mechanic swings the propeller, and the motor starts easily. While the propeller ticks over unfalteringly and the motor warms up, the instructor spends some time emphasizing to you the importance of following the foregoing procedure *in the proper sequence* when starting the plane. He then assists you in putting on and adjusting the earphone helmet, from which extend two rubber tubes leading to the instructor's mouthpiece. "You can't talk back to your teacher when you're wearing this," he says jokingly. "I'll do all the talking when we're up in the air."

Now the instructor prepares himself for flight. Through your earphones you hear him say, "All right, I'll taxi out to the end of the runway, so we can use all of the field for the take-off."

Now the instructor signals to the mechanic, who pulls clear the chocks that were blocking the landing wheels, and then, carefully avoiding the whirling propeller blades, runs to the right wing tip and catches hold of the strut. Another mechanic has grasped the strut of the left wing, and as the motor bursts into a roar they escort the plane to the edge of the apron. There the instructor signals them away and taxis on into the field to the end of the runway, where he swings the machine to face the wind. "We're headed into the wind, ready for the take-off and your first lesson," you hear him say through your one-way communication system. "Don't touch the controls until I get the ship up to a safe altitude. I'll let you know when you're to take over. Here goes!"

The motor roars; the machine begins to pick up speed rapidly, and the tail comes up like something alive. You look to the side and feel yourself charging across the flat grassy plain of the airfield. The earth is still close below you, but suddenly it starts falling away from you. A shocking realization is yours, and you may even speak it aloud: "We're flying!"

The first thrill is over. "I wonder how high we are already," you ask yourself, and start studying the instruments with a newborn interest. They mean much more to you now. The altimeter reading is 400 feet, and the airspeed indicator shows only 60 miles per hour, since you are still climbing. The voice of your instructor comes through the tubes, "Like it?" He has a nonchalant, easy air—and are you glad he's there in front of you! He levels the plane, makes a turn to the left, and begins climbing again.

You venture to look out of the cockpit and see the ground receding rapidly; it really looks far below you now. The fields with their varying colors have an artificially-laid-out appearance. Over to your left you see a farmstead whose main features are the rain-gray roofs. They are really rather near to you yet, but, oh, how far, far away!

You continue climbing. Your instructor speaks in a very normal tone of voice. "We're up nearly 600 feet now and still climbing. See how the nose is still up?" At 600 feet he levels the plane again, makes another turn to the left, and then sets the plane climbing again until the altimeter reads 800 feet. Then he levels the plane again, turns to the right, and climbs out to open country.

You spend your time now watching either the instruments or the easy bearing of your instructor's head. Some day perhaps you too will be an instructor.

"We're up 1000 feet now," says your instructor, just as you happen to note the 1000 reading on the altimeter. "It will be safe now for you to get a feel of straight and level flight."

You are listening intently and expect to be told at any moment to take over entire control of the plane, but your instructor has some important preliminaries to perform first.

"Take hold of the control stick with your right hand—just a nice, gentle hold. Got it? Now place the balls of your feet on the rudders."

You carefully follow the instructions as your heart beats a bit faster. But you have a resolute calm about you.

"Now I want you to follow my movements on the rudder and stick. This won't be hard at all. Don't look at the instruments or the controls; just keep looking straight ahead toward the horizon. See how the nose lies right on it now?"

"All right," he continues; "let's make the nose drop below the horizon. Gently forward on the stick now—gently and easily. See how the nose goes down? Now we'll bring it back up. Back on the stick, easy back. See how she obeys?"

You are thrilled. It is easy. At least this much is. You feel the stick go forward to a center position as the instructor levels off. He speaks again: "Now you try it. Do it a couple of times. Remember, work gently and keep looking ahead."

Now you are doing it. Stick forward, easily, gently. You see the nose move down. Stick back, easily, gently. The nose plays upward, meets the horizon, keeps coming up. That is far enough, you feel almost instinctively, and let her down again to the level of the horizon.

You repeat the procedure several times, proudly feeling that you are doing a good job with this first fluttering of your baby wings. As you again level the nose to the horizon and hold it there you expectantly wait for the praise you think will come from your instructor. But all he says is: "O.K., now we'll push the stick easily to the left and see what happens."

Your gentle grip on the stick follows it carefully to the left as your instructor continues: "See that left wing lower? Now we'll raise it level again." The stick moves back toward the right and you see the wing lift to a level position.

The instructor lowers and lifts the wing again; then he lowers and lifts the other wing, and you follow through on your stick in masterly fashion. You know your turn to do it by yourself is at hand. You are just a bit tense as the order comes. With stern understanding your instructor says: "Relax a little. Don't be so tense. You might as well be comfortable when you fly. Raise and lower the wings now, several times, until you are sure of what to expect." Simultaneously the instructor folds his arms complacently and looks nonchalantly out of the window. You are up to the situation—you are on your own. Avoiding a violent hold on the stick, and already getting a feel of just how to govern it, you raise and lower the wings several times each, until your instructor calls to you: "Fine! Now relax a bit and enjoy the scenery while I take the controls. See that village yonder with the big water tower? That's Summerville, in case you can't recognize your neighbor town from the air." And you are ready to admit that you didn't know it was Summerville. Uncle Jack lives in Summerville. Wouldn't he be surprised to know where you are right at this minute?

The instructor interrupts your thoughts about Uncle Jack. "Now I'll show you something that will surprise you. Look, I have my hands off the stick and my feet off the pedals, and still the ship is flying level." He turns and smiles at you. "An airplane, if it is designed properly, will fly straight and level without the pilot's touching the stick. If the plane should hit an air gust it might roll or pitch a bit, but it will right itself again without your help. Does that give you any more confidence in flying?" You nod your head smilingly.

Perhaps you are thinking: "A plane takes better care of itself than an automobile does."

Making turns. As you wonder what the instructor will do next he says: "Now let us try making a few turns. First I'll do a shallow turn to the right. You follow the controls with me." Almost with his words you feel a leaning motion to the right; you are following the stick to the right and you notice the right wing lower. From the instructions you have already received you anticipate your instructor's next words: "To turn to the right we push the stick to the right and give just enough right rudder. Now that we have our bank and our turn, we neutralize the stick and rudder. At the time we turn, the nose is still on the horizon. That's important." He straightens out the plane again and then makes a medium turn to the left, explaining the control movements as he does so. The ship level again, you get your order: "Now you try it. Remember, rudder and bank together."

For the next five minutes you practice turns. You learn to get the feel of the amount of pressure to apply to the controls rather than just the distance you need to move them. You learn that to get the ship back to level flight after making a turn you simply have to do to the controls just the opposite from what you did to get the ship into the turn. You are cautious to follow your instructor's advice about not attempting too steep turns at this early stage. "Steeper turns will come in a later lesson," he says. "The thing for you to do at this stage of the game is to get used to your ship."

Your first lesson is not without its disappointment, but it is seldom that a first lesson is perfect. On making a turn to the right you slip up on that important detail: *Keep your nose on the horizon while turning.* Somehow or other, instead of watching the nose, you are looking at the instrument panel. Suddenly the instructor calls, "Oh, oh, you're going into a dive."

Your head snaps up and you see the horizon sailing over your wing. "O.K., I'll take her," says the voice of your instructor, and he straightens out the ship to speeding-level flight. And you feel like—well, what does two cents feel like?

But hold on, you do redeem yourself. Instead of the instructor's calling it a day and taking you back to the airport with that let-down feeling, he quite sensibly gives you an opportunity to try two more turns. You do them beautifully and regain any confidence you may have lost by that almost inevitable first blunder.

So your first lesson ends. The instructor flies the plane back to the field, of which, incidentally, you have lost the direction. He makes a three-point landing and taxis to the hangar. You are again on the good earth, but you are sold on flying. "Nice job," says the instructor as he climbs out of the plane and looks you over. "I think you'll learn all right."

Further lessons. We have attempted thus far to give you some idea of what a first flying lesson is like. Since our purpose here is to give you only some beginning understanding and impressions of flying, it will hardly be necessary to describe further and more advanced lessons that student pilots take. On page 59 you will find several excellent references which treat rather thoroughly the various phases of learning to fly an airplane.

Mistaken ideas about flying. Now that you are on the ground again, let us chat about several things pertinent to flying which you should know if you are to become air-conditioned. Mind you, air-conditioning is for you, even though you never intend to pilot a plane, or even to ride in one for that matter. It is simply a matter of becoming informed about present-day civilization.

Air pockets. Have you ever heard anyone make some such a statement as this: "Mercy, I'd never ride in a plane. Imagine what would happen if it hit one of those awful air pockets."

The belief in the existence of air pockets is quite as unfounded as was the belief in the time of Columbus that a ship sailing far enough out to sea would suddenly plunge to destruction over the brink of the earth. In other words, there are no such things as air pockets—areas in the atmosphere where there is absolute vacuum and consequently no support for a plane. The term *air pockets* is really a misnomer for *air bumps.* In certain parts of the atmosphere the air may have a bounding, upward movement and then suddenly fall downward. This updraft or downdraft of the air may be caused by air striking obstructions as it moves along the surface of the earth in the form of wind. Or the cause of this up-and-down movement of the air may be due to heated air rising from the earth and cutting across the current of the existing wind.

Planes flying into areas of bumpy air, particularly light planes, experience a rocking or otherwise rough motion, but they are not endangered unless the gusts or bumps are exceptionally strong.

Engine failure. Many people think that, if the motor of a plane should suddenly stop when the ship is high in the air, all is lost. They imagine the plane falling straight to the earth as fast as the force of gravity can pull it. Not so. The well-trained pilot, on hearing his motor quit, merely brings the nose of his plane down just far enough so that the plane develops a coasting speed. Thus he can usually glide until he finds a field suitable for landing. In reality such an emergency landing as this differs from a normal landing only in that the pilot must land once he lowers to the field; he cannot regain speed, climb, and try again. But the dead motor, so far as a final landing is concerned, is really no different from the throttled motor which is necessary to make a normal landing.

The student pilot practices forced landings a great deal. If he is well trained, he has little to fear from them.

Stalls. A stalled airplane does not, like the stalled automobile, have a dead motor. It is simply in a state where it has lost its "life-giving," forward speed. Perhaps the pilot has made too steep a climb or too sharp a turn and has thus so reduced the speed of the plane that the airstream is no longer sufficient to support the plane. In such a case the pilot merely resorts to a dependable old practice—he lowers the nose of his plane until it picks up speed again.

The nothing-to-it idea of flying. There is a school of thought which would have everyone, particularly those who want to fly and can afford to buy a plane, believe that flying is an art which can be learned almost overnight.

It has been proved in recent years that any normal person can be taught to fly the conventional airplane provided he wants to put some effort into the learning and provided he obtains the services of a capable instructor who really goes to work to teach him. But it is a fallacy to say that one can learn to fly in from 5 to 10 hours. Nor can one learn to drive an automobile safely in this length of time. The average person who wants to fly needs a minimum of 8 hours of dual instruction prior to soloing in a conventional airplane. Most young folks solo in from 8 to 10 hours, but older persons may need from 15 to 20 hours of dual instruction before soloing.

After obtaining his license the pilot will continue to learn from experience, ever realizing that frequent flying, even for the mere sake of practice, is necessary to keep in trim.

As for you and your own flying, you will find that all your movements in the beginning will be more or less mechanical. But through repetition and practice your flying will develop from slow, deliberate movements to natural, instinctive ones. Pilots become capable through practice. To some, flying comes easier than to others, but even students with outstanding natural ability require a great deal of training. They, too, must exercise perseverance, together with a lot of good common sense.

Women can fly too. It may have seemed to you high-school girls who are taking this course in pre-flight aeronautics that up to this point we have been addressing only boys. But such is really not the case. Girls need to become "air-conditioned" too. And there are many among you who will in the near future actually become student pilots.

Perhaps you already know that there are many women in the United States with hundreds of flying hours to their credit. Are women pilots capable? You boys may be taken aback to learn that some inspectors of the Civil Aeronautics Administration proclaim that women students are often smoother fliers than men and that they are generally more conservative, more cautious, and more eager to learn than men.

The will to learn is distinctly in favor of the woman pilot. It makes her sincere in her efforts and hard-working in her attempts to gain the mastery she wants. Many critics have argued that women do not have the strength to fly, but it does not require great strength to fly a plane. As a matter of fact, it takes less effort to fly a plane than it does to drive a car.

There is definitely a place in aviation for women, either as pilots or in many of the related occupations.

The pilot instructor and you. If you undertake to learn to fly, your first act should be to obtain the services of a good instructor. For your protection he must, of course, have an instructor's rating along with his pilot's certificate. Don't take instructions from anyone merely because he is a good pilot; see that he also has an instructor's rating. Your flying career is most likely to be successful if you build on a solid foundation. A good instructor will help you lay that foundation. He will not only teach you the mechanical management of a plane, but he will also do much to guide you in cultivating desirable habits in flying.

Exercise 1. Your teacher will arrange for a local flying instructor or airplane pilot to talk to your class about learning to fly an airplane. Prepare a list of questions which you would like to ask this pilot about learning to fly. Listen carefully to what your visitor has to say, and write a brief report of his talk in your notebook.

Exercise 2. Your teacher will arrange for your class to make an observation of an airplane, possibly one that is privately owned in your locality. The owner or pilot of the plane will explain how it is operated, how the control surfaces work, and so on. Be prepared to ask questions about the plane and how it operates. Report your findings in your notebook. Make a sketch of the plane you observed, showing as many of the details of its construction as you can.

Exercise 3. Demonstrate in as many ways as you can how air can be made to provide a lifting support to flat-shaped objects. Example: Hold a piece of cardboard with the front edge tilted before an electric fan.

Exercise 4. If you are a builder of model airplanes, demonstrate to the class some of your models, showing their construction, explaining their control surfaces, and pointing out how they are able to fly (if they are flying models).

Exercise 5. Make a list of the physical and mental qualifications which you consider important to being able to fly a plane well.

Exercise 6. List as many reasons as you can why you think you would or would not make a successful airplane pilot.

Exercise 7. Make a survey among the people of your neighborhood to discover what, if any, misconceptions they have about flying. For example, do they believe in "air pockets"?

Exercise 8. If possible, interview someone in your neighborhood who is learning to fly. Find out about such things as the following:

a. The qualifications he or she needed in order to take instructions.

b. The cost of instructions.

c. The requirements necessary for obtaining his pilot's certificate.

d. How difficult learning to fly is.

e. The subjects one should study in high school if he intends to take pilot training.

Exercise 9. Discuss in class the advantages or opportunities which learning to fly an airplane can give.

Exercise 10. Find in the advertising sections of aviation magazines the names of several aircraft manufacturing companies Write to some of them asking for any free literature they have concerning their airplanes for private flying. When you receive the material, work in class committees to study and report on various parts of it.

Problem 2. How enjoyable is flying?

A trip by air. This is the day we have been waiting for. We are going to take a trip by air, a non-stop trip from New York to Chicago in a great blue-and-silver transport plane, and convince ourselves of the convenience and enjoyment of air travel. There is not a cloud in the sky to disturb the brightly shining sun; the day is a perfect one for our journey.

Courtesy Transcontinental & Western Air, Inc.

Fig. 4. Buying tickets at the Airlines Terminal, New York City

At the Airlines terminal. We begin our trip to Chicago at the "Union Station of the Air," the impressive Airlines Terminal deep in the heart of New York City. We made reservations for seats by telephone the day before; now we pay for our tickets and have our luggage weighed. We are making our arrangements early so that we may have some time to spend at the airport before our plane takes off.

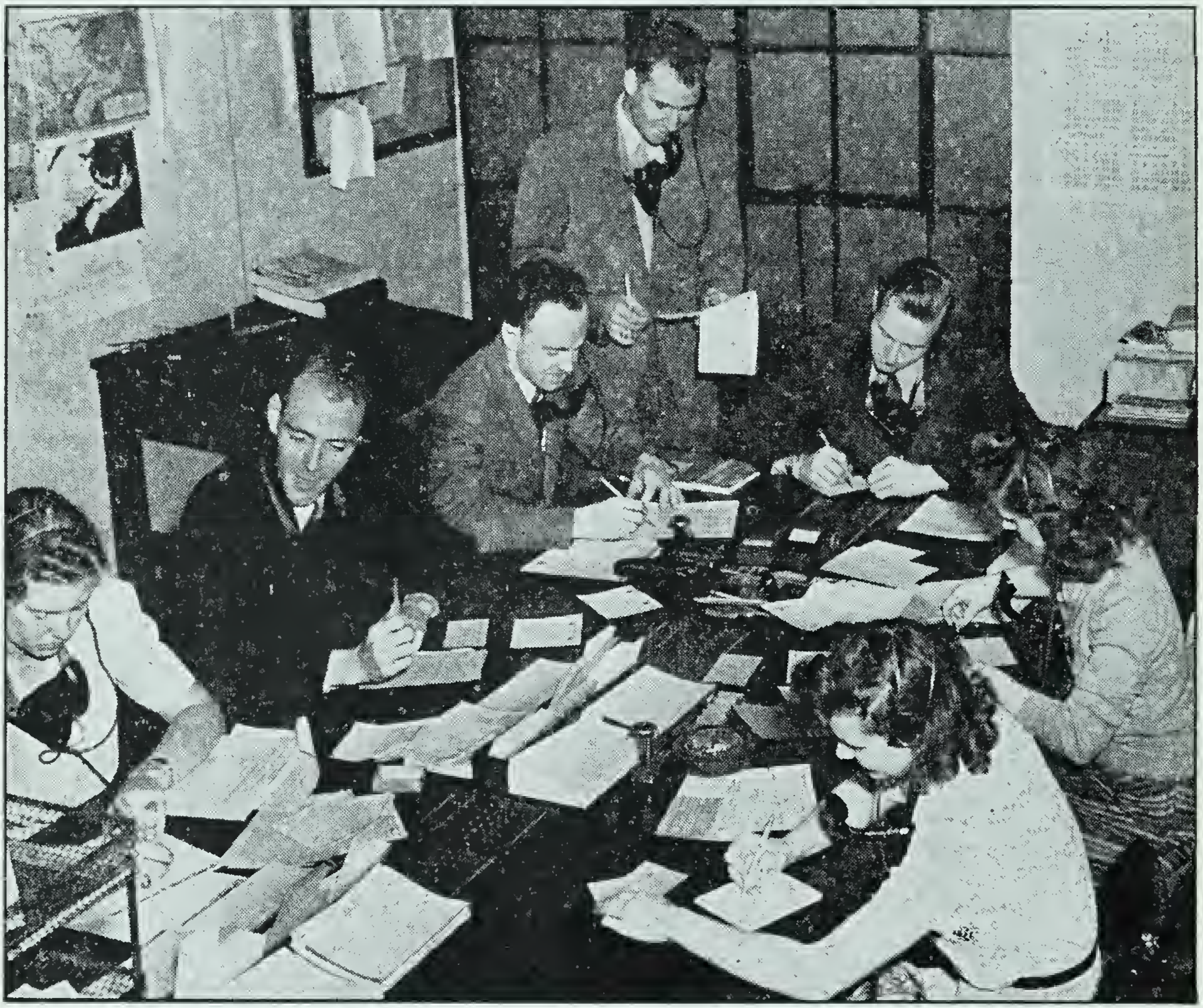
As we enter the Terminal we are greeted by air maps of the world before which a number of people stand studiously. We need not climb a stairway to the luxurious waiting room above. Instead, an escalator, or "traveling stairway," takes us up, and suddenly we find ourselves in a spacious circular room. We see the information booth surrounded by ticket counters and routing and reservation desks. A hum of activity surrounds us—porters hurrying by with baggage, neatly dressed people going to the ticket counters to ask questions of the expertly trained officials whose chief concern is the comfort and convenience of air travelers.

We find as we buy our tickets that the purchase price, which is approximately the same as for first-class railroad fare, includes not only passage in the plane but also the meals which will be served us on the plane. In the meantime our baggage has been taken by the porters to be weighed, checked, and placed in the luggage compartment of the limousine which will take us to the airport for an extra charge of $1.00. We are each allowed 40 pounds of luggage, which will be carried free of charge on the plane. We, too, must give our weight, but whether we are thin or fat makes no difference in our fare. The transportation officials merely want to know the exact amount of the plane's total "pay load."

With these preparatory matters attended to, we may relax in the gay lounge or restaurant of the Terminal. Or, if we wish to be entertained during the time we have left before the limousine departs for the airport, we may seat ourselves in the 600-seat Newsreel Theatre specially provided for the enjoyment of air travelers. Which do you prefer?

La Guardia Field. The time for departure to the airport arrives. The starter notifies us, and we step into the limousine with the other passengers as it waits in the main concourse of the Terminal. Neither we nor the porters need to carry our baggage; automatic conveyors carry it to our car for us.

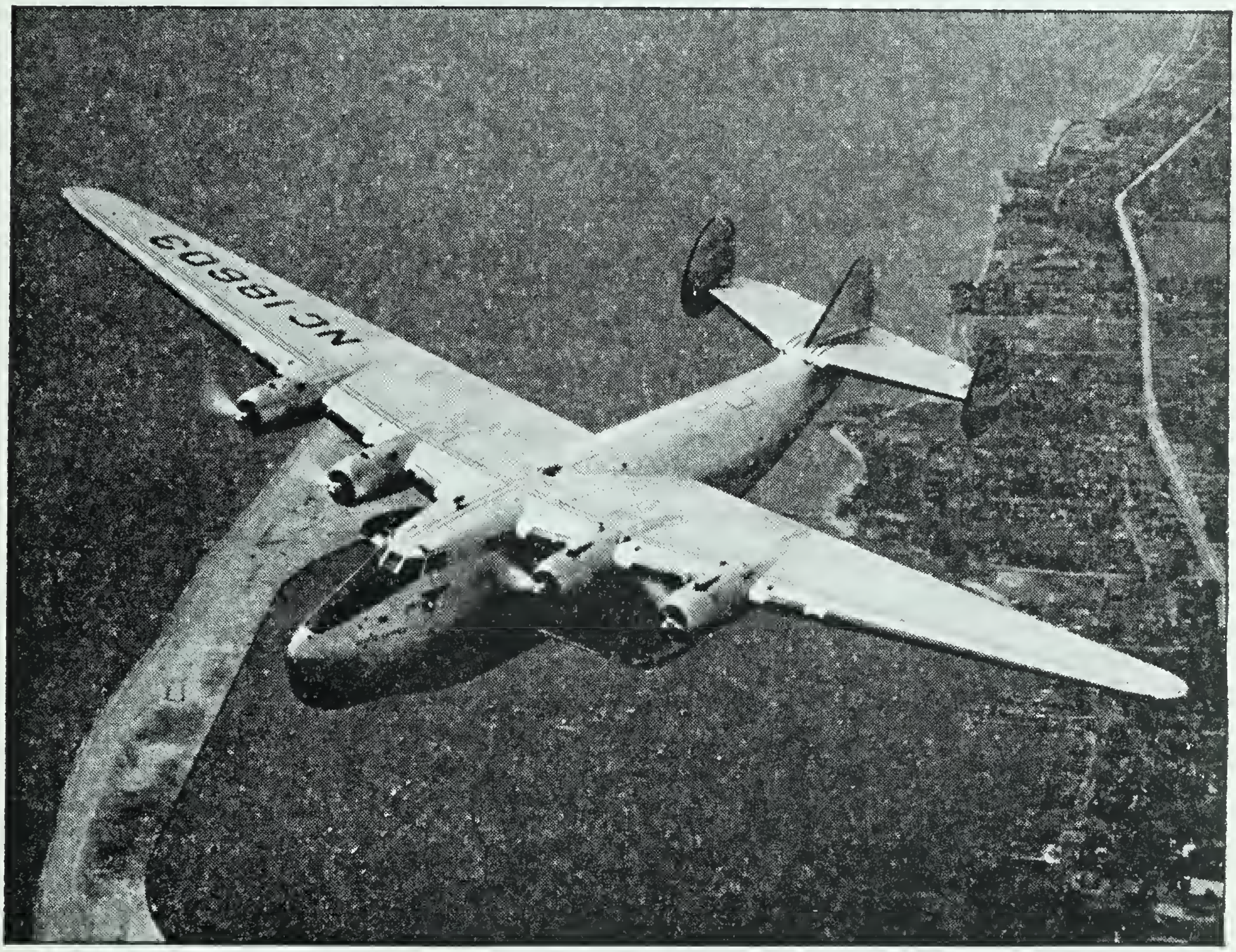
Soon we are passing through the busy streets of the city. We drive over one of the giant bridges that stretch over the East River and connect Manhattan with Long Island, follow a drive along the edge of the water, and in a few minutes the airport lies before us—New York Municipal Airport, La Guardia Field, its broad, brown expanse covering an area of nearly one square mile, over half of which has risen out of the waters of the bay, man-made. A slogan which this field has is "A plane every minute." Here an average of nearly 250 airliners is scheduled for regular daily departure and arrival. Around five o'clock in the evening an airliner arrives or departs every fifty-six seconds at this magnificent air depot. That gives you some idea of the popularity of air travel.



Courtesy Northeast Airlines, Inc.

Fig. 5. Passengers arrange for seat space by telephone to this reservation department

Our plane will leave in an hour, and so we may stroll for a time along the rather crowded observation decks of the Administration Building. The sight we behold draws from us oh's and ah's. We see glittering airliners sweeping across the blue, writing a story of speed and safety for us. The sky is literally dotted with silver planes, and there is an incessant droning of motors. Great runways for land planes extend into the field in various directions like the spokes of a wheel. The largest of these is 300 feet wide and 6000 feet long. (That is a length of more than one mile!) Airliners sweep along these ways, great silver birds with steady wings, and on one side of the field we see a row of passenger planes crouching, waiting their turn to take off. They, together with the continual incoming planes, are ready to accommodate the thousands of people who a very short time ago would not have thought of flying but are now accustomed to it.



Courtesy Pan American Airways

Fig. 6. The Yankee Clipper leaves the last stretch of land and heads for distant ports

Over at the farther end of the field we see the Marine Terminal. This is where the giant seaplanes land when they fly in from foreign lands. Several are tied up at the dock now. Perhaps one of them is the *Yankee Clipper.*

If we should look from these observation decks at night, the scene would be a brilliant showplace to us. Great floodlights sweep over the land, sea, and skies to make landings and take-offs safe. The impressive buildings are outlined with red lights, and the runways are radiant. Even the windsock above the observation tower, which indicates to pilots the direction of the wind, is outlined by red lights. At the end of each of the runways two narrow-beam floodlights pierce the skies, each with 7,500,000 candle power!

The airport is a beehive of activity. To manage the great stream of air traffic—people and planes coming from all parts of the United States (and the world, too)—an organization of over 4500 employees has grown up. This is enough people to populate a good-sized town. And, like a town, La Guardia Field has restaurants, news stands, a florist shop, barber shop, a fire department, telegraph offices, a post office, a weather bureau, first-aid stations, and a photographer.

Visiting a hangar. We are anxious to see more than just the outside activity of the airport. A guide takes us to one of the half dozen or more hangars on the field. What large garages for planes! Each of them is large enough to accommodate a football game, audience and all. They have high curved metal roofs and massive sliding doors of heavy metal. The guide informs us that each of these doors weighs 25 tons!

As we stand almost in awe before the hangar a little tractor busily put-puts up to us, whirls around, and backs into the building. Some men hitch the tractor to the tail of an airliner, and in a moment the great plane is towed out into the sunshine and turned around in front of the hangar. Two men appear with wooden chocks and block the giant wheels of the plane so that it cannot move. Meanwhile, the tractor is uncoupled and scurries away to do something else.

We go into the shelter of the great hangar, where we see a crew of men busily checking one of the multimotored planes in the foreground. Some are on platforms inspecting the motors and the propellers. One is testing the aileron and rudder controls. Others are working on the instrument panel. We learn from the guide that there are hundreds of items on the control panel which pilots need to watch and work while the plane is in flight. We learn, too, that after a motor has performed for 625 hours, it is taken apart and minutely examined, even though it may still sound in perfect running order when brought in. If any parts are found to be damaged in the least, they are replaced with new parts. The mechanics even have machines that can "look" through metal as though they had eyes. These machines can detect a flaw that even a microscope could not show.

During an inspection every square inch of the plane is scrutinized. We come to appreciate the great care which the air transportation industry takes in seeing that its planes are made and kept safe for its patrons.

The airport weather station. The guide takes us next to the weather station, where we see the weather man and his helpers. Here everyone is at work. Men are seated at tables with large maps spread over them. Large maps of the United States are on the walls. The guide steps over to one of them and shows us the weather stations located all along the airways. These, he informs us, send in weather reports hourly. He points to the teletypes busily clicking like typewriters and tells us that the messages which they are printing on long strips of paper are weather reports coming in from all over the country. At other teletypes sit operators who are sending weather reports out to airports the country over, telling what the weather conditions are in New York.

Some time before a plane takes off, the pilot receives a complete weather report, or *trip forecast,* from the weather station. Thus the pilot knows beforehand what the weather is along his route and what it will be for some hours to come. If conditions are too severe at any point, he may re-route his course. In addition to knowing the weather conditions the pilot may learn also from the weather station how high to fly to find smooth air, so that the journey will be a comfortable one for the passengers. If the pilot knows, for example, that strong winds are blowing at an altitude of 4000 feet, while only an easy breeze exists at 6000 feet, he will, of course, travel at the latter altitude. The guide further explains that ships flying west must travel at even thousand-foot levels—at 4000, 6000, or 8000 feet. On the other hand, ships flying eastward must travel at odd thousand-foot levels—at 3000, 5000, or 7000 feet. Thus the skyway provides one-way roads for planes.

The airport Control Tower. A glance at our watches tells us that time for our plane's departure is drawing near, but we still have time to visit another very important and interesting part of the airport, the Control Tower high on top of the Administration Building. The guide points out the tower to us as we approach, and tells us that from it the traffic on the airport is controlled. In it the traffic policemen of the air do their work.

It seems like a long climb, but we reach the tower at last. It is entirely inclosed in glass, and as we step inside, careful not to be noisy, we are transfixed by the view of the airport and the country for miles around. There on the field and runways before our eyes we see some of the world's greatest flying ships—ships of the Great Silver Fleet of the Eastern Airlines bound for the Southland; Trans-Canada airliners; Boeing Stratoliners of the Transcontinental airline; ships bound for Montreal on the Colonial Airways; 12-ton mainliners of the United Air Lines scheduled for San Francisco.

There are several men in the glass-walled room. Some of them are writing at tables. One is standing with a microphone in his hand peering over the airfield. The men are friendly, but they are too busy to talk with us very much. The guide explains the equipment used in controlling the air traffic.

We learn that the score or more of large radio loudspeakers along the walls bring in information from all parts of the continent, as well as messages from the pilots coming in to land or preparing to take off from the field below. A very loud and rather croaky voice comes through the speaker of one of the airlines: "NC 2 8 calling La Guardia Tower. Ready to taxi. Departing for Baltimore. Flight plan given to airways. Go ahead."

The man with the microphone peers intently at the airfield for a moment, looks at two big glass dials which indicate the velocity and direction of the wind, and then announces to the pilot through his instrument: "La Guardia Tower answering NC 2 8. Wind north six S-six. Repair truck at center of field. O.K. to taxi out. Go ahead." The announcer gives another message when the pilot has reached the point of take-off, and then leaves the microphone and points out the plane to us. Flight 28 is beginning. The pilot gives the engines the "gun," and the motors roar. The plane starts to move like a monster beetle, gathers speed, and soon is racing, tail level, down the runway. It lifts gracefully into the air and straightens to its course. Flight 28 is on its route.

Now the loudspeaker of another airline operates, and as the announcer moves to his microphone to answer he points to a small speck moving in the distance above the horizon. The plane is so far away that we can barely see it.

We see what a busy job it is to direct the traffic of the air. Orders must be given nearly every minute. Sometimes the orders must be given by means of a powerful signal light that flashes messages by means of two different-colored lights, one red and one green. The pilots of planes which have no radios are able to receive these signals even in broad daylight. They acknowledge receipt of the signals by rocking their wings while in flight and by moving the ailerons or rudder, whichever is most easily seen from the tower. They circle the airport until they get the green light, which means it is safe for them to land.

As soon as a radio-equipped plane comes within fifteen miles of the airport the pilot tunes his set to the wave length of the airport station and begins to inquire about landing. He must obey the orders he receives from the control station, else a traffic accident may result. The traffic-control official guides the pilot to use the runway which will enable him to land against the wind. If the runway is being used at the time, the pilot must circle the airport, always to the left, until the runway he needs is unoccupied.

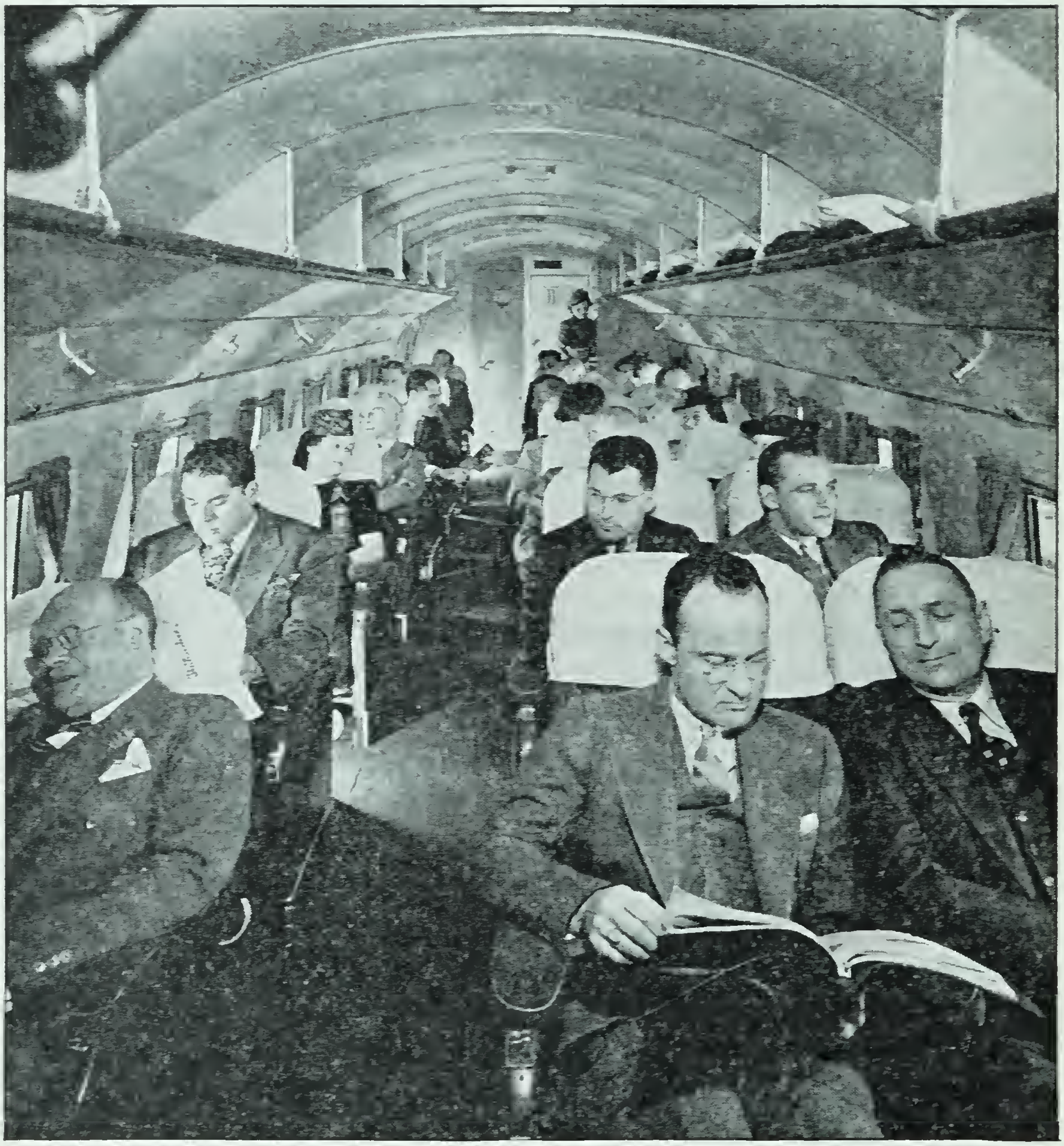
At night the traffic operator must control all airport lighting. Beside the desk at which the man is writing is a large panel which has nearly a hundred switches. These switches control the floodlights, runway lights, and lights at the edge of the field.

All aboard for Chicago. It is nearly eleven o'clock, the time for our plane trip to Chicago to begin. As we leave the Control Tower we hear the voice of the announcer roar out over the loudspeaker: "Plane No. 30 now loading. Passengers for Chicago will please go aboard!" This is our plane, a magnificent twelve-ton liner that shrinks the 3093 railway miles between New York and San Francisco to 2639 airway miles; that reduces the railway time of 59 hours to flying time of 19 hours.

The plane is ready, and so are we. Our glittering blue-and-silver mainliner, with its 95 feet of wing span, wheels into position, its propellers flashing in the sun. Baggage has been weighed, checked, and loaded; mail and express shipments are on board. Although thousands of flights have been made before this one, and flying has become commonplace, this is *our* first flight. Our adventure westward over the clouds will take us over a course charted by Indians, explorers, and creaking covered wagons.

The pilot peers from a window in the cockpit section of the plane, radio earphones over his head. We are slightly jittery, but we manage to assume an air of composure as we tell the stewardess in the trim light blue suit our names. She flashes a smile—a smile that we'll remember long after the trip—checks our names against the list of twenty passengers which she received from the passenger agent, and tells us to step in and choose any seat we wish.

Here we are in the passengers' cabin, so roomy that it reminds us of a Pullman car. Rows of reclining chairs on the right and on the left rest on a generous soft blue rug. We walk down the long aisle in the center and select seats near the front. They are no more comfortable than the others, but from there we can see better because the great broad wings will not obstruct our view. The stewardess shows us how to adjust the backs of the chairs so they will tilt back to the position most comfortable for us. We may adjust them, and



Courtesy United Air Lines

Fig. 7. The interior of a United Air Lines 21-passenger Mainliner

then read, nap, or enjoy the view of clouds, sky, and land. Over our seat extends a long rack which we may use for hats, coats, and small packages.

The take-off. Now a sign in green lights flashes over the door leading to the pilot's compartment. The sign reads: "No Smoking" and "Fasten Your Seat Belts." The stewardess goes quickly into her routine of assisting us to strap the belts across our laps. She informs us that the belts are used only for take-offs and landings, in case there should be any bumps. But she assures us that such is seldom the case. When the plane is on its course we may loosen the belts if we wish.

We hear the twin motors roar as the pilot gives them the "gun." Slowly and deliberately the plane moves around until its nose points down the field. As it does so the mighty propellers send a sweeping blast of air at the onlookers who stand behind the railing, and they clutch quickly at their hats to keep them from blowing off.

We roll along to a corner of the field, swing around, and head upwind. Just before the plane reaches the runway it stops, and we wonder what the trouble is. But everything is all right; the pilot has merely stopped to await the "go" signal from the Tower and to give the engines a final test. He "guns" each while the other is idling. Now they are both humming. A man sitting across from us puts a cigarette to his lips, but the stewardess points to the "No Smoking" sign ahead. "No smoking during take-offs and landings," she admonishes kindly.

As the traffic tower light blazes green the propellers whine and the motors roar at high pitch. The ship moves and gathers headway; the tail lifts until the cabin floor is level, and we begin to sense the thunderous forward drive. Through our windows we see the runways streaking by. Ten seconds pass, and at a speed of 90 miles an hour the plane suddenly seems to stand still; it has risen from the ground. The concrete runway drops below. First flighters, we are flying!

The broad strong wings of our ship take a generous bite of air, and it climbs higher and higher. The earth seems to rise up at us, and telegraph poles, trees, and towers reach for our windows when the plane banks to turn on its course to Chicago. But there is no alarming motion inside our comfortable room.

The airport is behind us now, and the plane continues to gain altitude. Far below us we see the stalwart skyscrapers of New York, and church spires point up at us like needles. The metropolis looks much more like a map of New York than like the city itself. We see the Empire State Building towering in vain to equal our height. The river below us–the Hudson River, about which we have read in our large geography books at school–is but a silver ribbon. The city drifts slowly into the background, and our plane picks up speed.

The "No Smoking" sign has been turned off from the pilot's cabin, and now the man who was cautioned by the stewardess about smoking lights up, as do several of the other passengers. There is no discomfort to any of us from the smoke, since the cabin is scientifically ventilated.

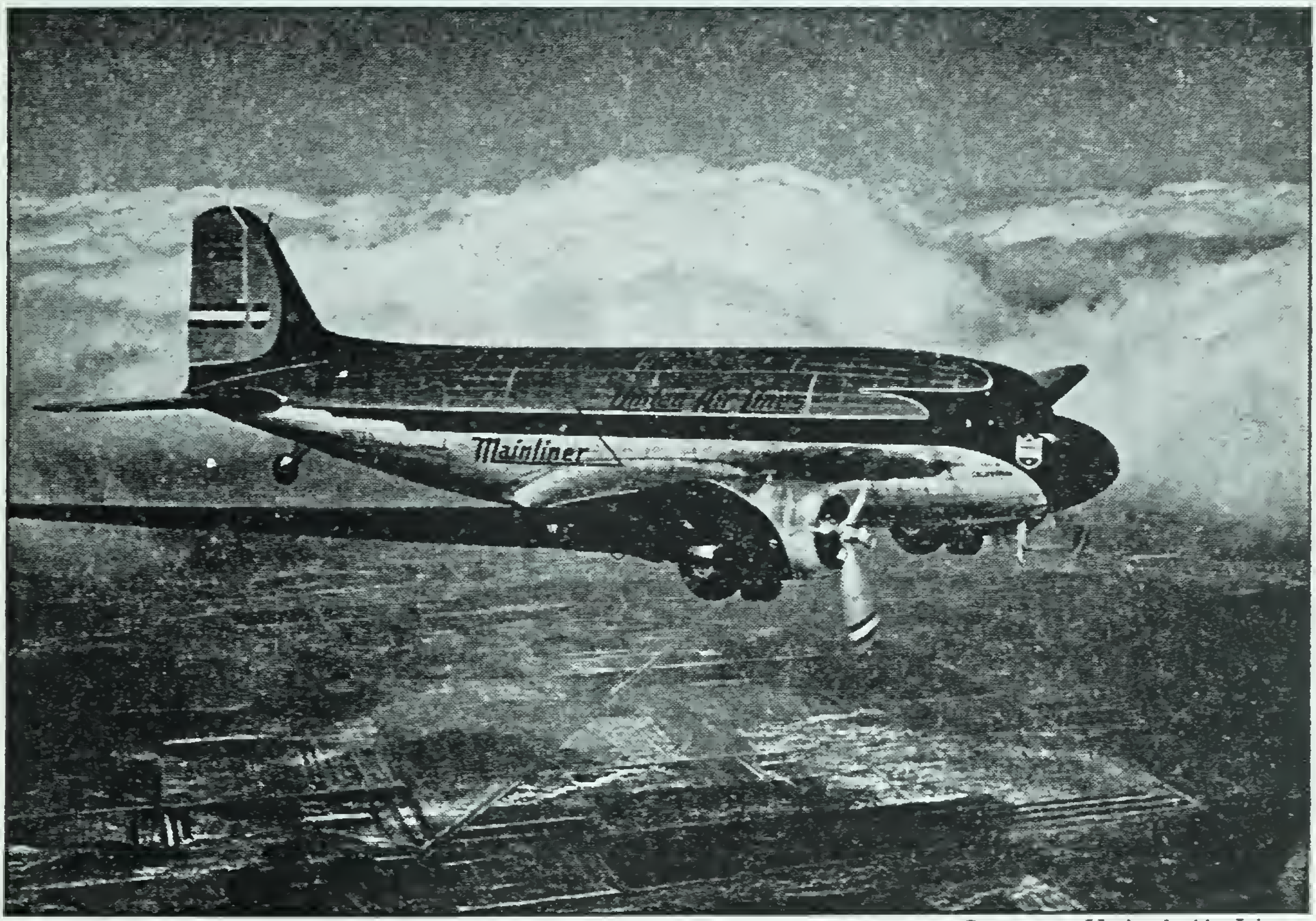
Courtesy Transcontinental & Western Air, Inc.

Fig. 8. You can relax and feel "at home" while traveling on an airliner

On our way. Soon we are passing over the State of New Jersey. Our cabin is so well sound-proofed that we may chat in ordinary voices about the things we see. We are 4000 feet in the air now, but we have no giddy feeling of height. We are traveling at nearly 180 miles per hour, but there are no highway, no traffic, no houses rushing past the level of our window to provide perspective and give a realization of speed. But if we look toward the earth and count the section lines that mark the mile boundaries, we find that we are crossing at a rate of nearly three a minute.

The stewardess passes down the aisle with chewing gum, magazines, and newspapers. She assist us, too, in unfastening our seat belts. Most of the passengers to whom air travel is a common experience settle back comfortably into their luxuriously upholstered chairs and make themselves at home.

But air travel is new to us. We want to see what the world "down under" looks like, and so we press to the windows. The countryside is a gaily cartooned pattern of woodlands, darkly cultivated fields, and broad, green cropland. Of course, the distance from which we look at things below shrinks them, obscures their details, and makes them appear strangely different. The highway beneath us looks like a rubber band, and the cars on it like crawling ants. The village beyond seems to be made of building blocks. Its connecting roads and highways hold it in a network. All is laid out before us. The man working in the field with the horses looks as though he is only several inches high. The lake beyond resembles a playground pool. There is an orchard; the trees look like rows of oddly shaped buttons sewed on a card. The cattle grazing in the green-carpeted pasture look like a flock of gnats. We gaze with ever-new interest as the plane speeds on.



Courtesy United Air Lines

Fig. 9. One of the United Air Lines Mainliners that link the key cities from coast to coast. It carries passengers, baggage, mail, and express at a cruising speed of 200 miles an hour.

Our first hour in the air has nearly passed. Off in the distance we see the smoking stacks of quite a large city. We take a map from the pocket of the seat to find out what city it is. The stewardess comes out of the pilot's compartment and passes down the aisle to us. She sees us searching on the map and hands us a slip of paper she has just received from the co-pilot. It shows us our exact location. The town we were wondering about and which we have now passed was Williamsport, Pennsylvania.

Luncheon on the airliner. The aroma of fresh hot coffee drifts down the aisle, and we go to the washroom to tidy up a bit before lunch. On our way we get a glimpse of an amazingly complete and immaculately clean kitchenette. Here bottles of beverages, cold and hot, and steaming potatoes, vegetables, and meat are kept at proper temperatures until mealtime. We have already learned from reading that the menus on our plane change every day. Here is what the stewardess spreads before us on a spick-and-span white tablecloth, steady and upright in our smooth 180-mile-per-hour flight: chilled cantaloupe cocktail, roast chicken, browned new potatoes, fresh spring vegetable salad, hot rolls, French dressing, raspberry sherbet with cookies, beverage, and mints. And once we thought that air travelers had to live only on sandwiches during their trip!

Courtesy Transcontinental & Western Air, Inc.

Fig. 10. Passengers enjoying themselves aboard an airliner

Mountains, clouds, and countryside. Luncheon over, we watch the Pennsylvania countryside slip beneath our smoothly speeding plane. Now we are crossing the first ridges of the Alleghenies. We had expected these mountains to look wild and rugged, but they really are quite tame in appearance. They remind us of the long welts indicating mountain chains which we used to see on the physical maps in our geographies. The mountains are, for the greater part, heavily wooded to their tops. The broad valleys between them, with their level and fertile farms and fields, would provide suitable landing spots for our plane.

There are a few scattered clouds in the sky now, and as our ship climbs to a higher altitude it rips through an occasional cloud mass and leaves it swirling behind. As it does so, we feel just a slight bump, occasioned by the fact that these clouds are really the tops of rising columns of air. Some of the clouds resemble wisps of snowy fleece. They are part of our new surroundings in this world of the air. Occasionally the heavier ones take on characteristic shapes—profiles of giant faces with enormous hooked noses, roosters with outstretched wings about to crow, gigantic camels. We have a great deal of fun pointing out the monstrosities to each other. One man is taking pictures of them with a motion-picture camera.

Three hours of our journey hurry past, and we have had an opportunity to recall many of the facts that we have learned about geography and history. The stewardess has pointed out many landmarks and features of America. Now our ship nears Cleveland, Ohio. The great city lies beneath us.

Off to the north we see the blue shores of Lake Erie and what must be Cleveland's lofty Terminal Tower, dwarfed from our height. A half hour later Toledo drifts by. We see its gray outskirts and the airport. Farther ahead we catch a view of the lake front and the great *V*-shaped mouth of the Maumee River.

Chicago, our destination, lies 230 air miles ahead. We speed over Ohio and cross the boundary to Indiana. Several of the passengers are napping over newspapers and magazines; others are admiring the beauty of the landscape below, enchanted by the sliding change of scenery. Presently the door to the pilot's compartment opens, and the Chief Pilot steps out for a bit of relaxation. He accepts a cup of coffee from the stewardess, walks leisurely down the aisle with it, and asks us how we are enjoying the trip. He is a figure that inspires our confidence.

The waters of Lake Michigan are vague in the distance now. As they become more and more visible the lake shore draws in toward our course. Soon we are abreast of Valparaiso, Indiana, and we may see the giant sand dunes lying in mountainous windrows along the beach. We pass over Gary, Indiana, and see the smoke rising blackly from its steel mills.

Chicago ahead. For some time we have noticed that our ship is reducing its speed. Chicago is about fifty miles distant, and the pilot is gradually "nosing" the plane downward on a long "hill" to the end of our journey. He does so in order that the passengers may suffer no discomfort from a rapid change in atmosphere. We feel the change of pressure in our ears—a slight buzzing noise—but by following the suggestion of the stewardess to swallow or yawn two or three times we rid ourselves of the feeling.

Courtesy Colonial Airlines, Inc.

Fig. 11. Meals aloft are furnished by the airline without extra charge

The "Fasten Your Seat Belts" and "No Smoking" signs are gleaming again, and there lies Chicago ahead of us—the air hub of America, with routes to the north, south, east, and west. The city stretches for miles and miles, its hundreds and hundreds of tall buildings standing, toylike, on a smooth floor. We see trains, tracks, bridges, and automobiles. The smoke rising from factory stacks spreads a gray-black haze over some sections of the city.

Up in the cockpit at this time our pilot has probably switched his radio to the wave length of the control tower at the Chicago airport, and is getting information about landing. Directly ahead of us is the airport. We are still flying at 1200 feet, dropping lower and lower. The plane speeds on past the airport and makes a great circle, its motors throttled down to 100 miles per hour. The pilot apparently now has his O.K. from the tower to land, for, headed into the wind, we drop slowly down to the end of the runway like a settling bird. We see the people looking toward us as we come in. The landing is so smooth that we can hardly tell when the ship touches the runway. Gradually it loses momentum and, with propellers whirling and engines throttled, finally rolls to a stop. The pilot throttles up the motors again, swings the plane around, and taxis to the terminal gate. We unfasten our seat belts, and the stewardess stands ready to assist us as we step from the ship into the strong sunlight and the welcoming throng.

Our pleasant journey from New York to Chicago by air is at an end. We have traveled 748 delightful air miles in slightly over five hours. We are experienced air travelers now, and shall recall, in the days to come, the personal attention, agreeable company, wonderful views, and restfulness of the trip. The skyway *is* intended for man as well as for birds.

Note to student. The sketch of the airport and trip given in this problem are exemplary of conditions and activities in peace time. The conditions brought about by the present war have changed many things, among them these: Passengers cannot look out of windows when taking off or landing and when passing certain military locations. Nor can they travel freely, and in some instances not at all, owing to priorities being extended to all military and government personnel and to businessmen when on war errands.

Meals are being curtailed. Sleeper planes are being converted into cargo carriers. There are no longer non-stop trips between New York and Chicago; all planes must stop at Cleveland at least, and usually at other places en route.

Visitors cannot see the inside of hangars. Soldiers are on guard. Blackouts change the appearance of the airports at night. No cameras may be carried on planes. Not nearly so many planes enter and leave La Guardia Field as do during peace time.

Exercise 11. If you have ever flown in an airplane, tell the class of your experience.

Exercise 12. Make a survey of your community to find a number of people who have traveled by commercial airliners. Work in committees or individually to interview a number of these people about their experiences in traveling by air. Report your findings to the class.

Exercise 13. If there is an aviator among your acquaintances, arrange with your teacher to have him speak to the class, telling them how the earth looks from the air.

Exercise 14. Write to several commercial airline companies asking for travel folders, transportation rates, travel schedules, and other literature they may have about their facilities for air travel.

Using this material, plan a trip by air which you would like to take. Show on a map the route you would follow. Point out in your writing of this trip the points of interest—commercial or industrial centers, national beauty spots—you would pass over or stop off to visit. Estimate the time the trip would take, your transportation costs, and any other related items, such as where you would take your meals and where you would sleep; show also the plane conveniences you might enjoy, and describe or sketch, if you wish, both the interior and exterior of the airliner in which you would travel.

Exercise 15. If it is possible, your teacher will arrange for a visit to a local airport. Work in committees to find out all you can about such items as the following:

a. The size and arrangement of the airfield, its runways, administration building, hangars, and other facilities. (Sketches may be made of the field.)

b. How the traffic of the airport is controlled, together with amount of traffic at the field in a day.

c. Rules and regulations of the airport.

d. Particular uses made of the airport. Is it a mail station? an airline depot? a field primarily for the use of local aircraft?

e. Occupations carried on at the airport.

Exercise 16. Find out all you can about major airports in the United States from books, newspapers, magazines, and interviews. Report your findings to the class.

Problem 3. How is air travel made safe?

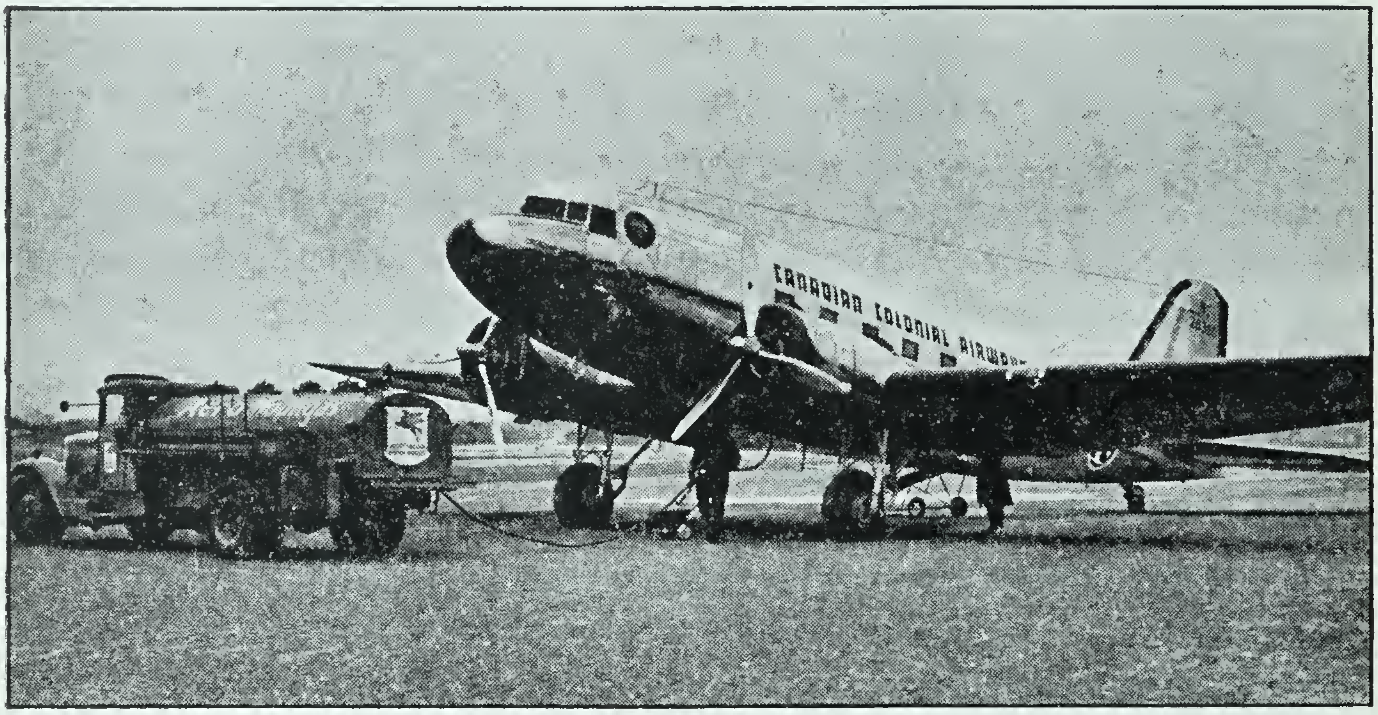
It is approximately four decades since the Wright brothers made the first successful effort to fly, and barely skimmed the ground at Kitty Hawk, North Carolina, to amaze a skeptical crowd of observers. What progress aviation has made since that memorable-to-flying year

1903! From crude experimental aircraft capable of only short, uncertain flights it has advanced to streamlined wonders capable of traversing oceans and continents surely and speedily. For us aviation has produced a new world, so far as travel is concerned. Our new world of the sky is a common thoroughfare of great aerial transportation, unbounded territory offering invisible highways to thousands of commercial and pleasure planes as well as to thousands more of military flying craft.

The planes of our seventeen domestic airlines are today affording transportation to more than four million persons annually between more than two hundred centers on schedules operating twenty-four hours a day seven days a week. This enormous amount of passenger travel by air is significant of the trust which Americans have in the safety and efficiency of modern passenger planes. Thanks to the genius of science, modern equipment and modern aids to safety have been made available by the airlines, enabling them to achieve a safety record surpassing that of any other form of transportation. Recently during a period of one and one-half years one billion passenger miles were flown by the airlines of the United States without a single fatality either to passengers or crews. The size of the figure "one billion miles" means more to us when we think of it in terms of how many times we should have to cross the United States from east to west to total that many miles. Figure it out.

The record of safety achieved by the airlines has not, of course, "just happened." To begin with, air-transport planes are not constructed stingily. From their powerful engines to their delicate instruments they are built of the toughest and most durable of materials. We think of expensive automobiles as being constructed of superior materials and being delicately adjusted, but the transport plane is unbelievably superior to them in construction and adjustment. Our better automobiles will run from 50,000 to 100,000 miles, and then require a rather extensive overhauling and replacement of parts. But transport planes are so durably constructed that they can easily fly one and three-quarter million miles, the motors singing in excellent condition the last mile.

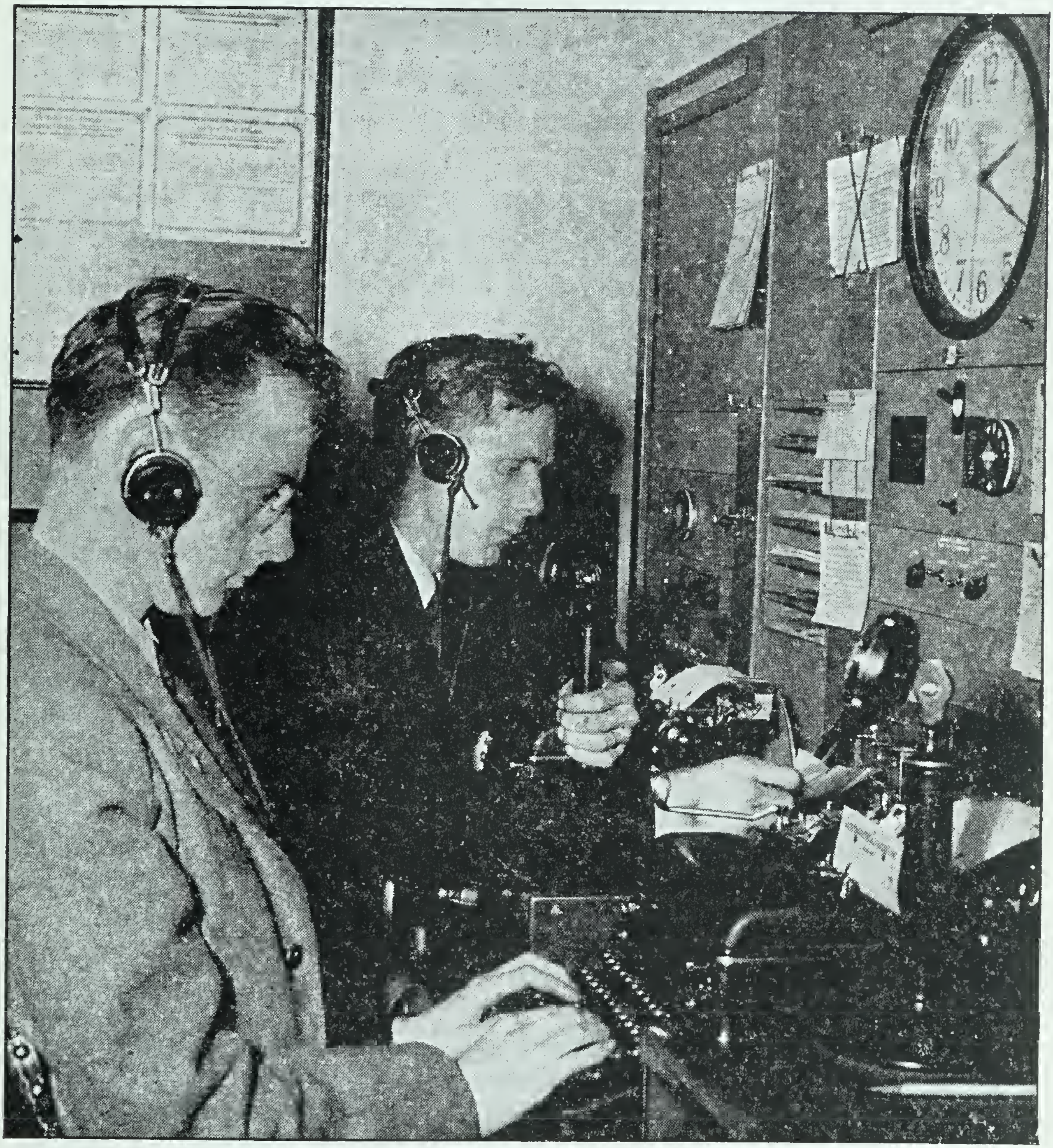
To the excellence of plane construction we must add the consistent care and watchfulness of pilots and assisting ground personnel. Vigilance and painstaking care are watchwords of airway travel. The great liners flying 8000 feet or higher on their route from New York to San Francisco may seem to the average onlooker to be isolated things on uncharted ways, taking countless chances of meeting destruction. But, as a matter of fact, for each of these airliners in the seemingly remote heavens there is a ground crew of more than seventy-five experts directing and recording every mile that the liner flies. The plane is not "alone." Fast teletypes are relaying information to the pilots, describing how to avoid any hazards and telling of the general flight conditions of the skyway ahead. The pilots are in two-way conversation with ground stations day and night. Every twenty minutes the co-pilot of the flying ship sends by radio a position report to the nearest ground station along the line. In this report he gives, along with his location, the altitude at which the plane is flying, the temperature of the outside air, and the general weather conditions. From this information the company's dispatchers are able to follow the progress of the plane and to ascertain its exact location at all times.



Courtesy Colonial Airlines, Inc.

Fig. 12. Airliner being refueled by gas truck. The truck and long hose are used for refueling to prevent injury to the plane that might result from hitting the plane against a stationary gas pump.

In 1941 there were 414 airway and air-report stations in the United States providing sources for weather reporting to the airlines. In the same year 29,422 airway miles were provided with teletype service which supplied instantaneous reports on the weather to planes. Thus, the pilots guiding modern passenger planes flying at three miles per minute are enabled to know just what weather conditions are 100 miles, 200 miles, 400 miles ahead—distances which they will very soon be covering. Should the weather report indicate dangerous flying conditions ahead, the pilot may "sit down" with his passengers on one of the emergency fields which the Federal Government has provided every thirty to fifty miles along the line.



Courtesy Northeast Airlines, Inc.

Fig. 13. These men use radio to call a plane in the air as quickly as you can call your neighbor by telephone. The pilot in the plane can call back just as quickly.

Unnoticed by the average day air traveler as his plane rides high over American countrysides are the frequent windmill-like steel towers that provide guiding lights for the pilot at night. These towers are topped with revolving beacons, two feet in diameter, which pierce the sky with 2,000,000 candle-power beams and thus blaze a sky trail for pilots. Between Chicago and San Francisco these beacon towers, or "lighthouses" of the airway, occur at intervals of ten to twenty miles. Some have been built high on hilltops and mountain ridges; others are located at the intermediate, or "emergency," landing fields. The beacons located at landing fields indicate that fact to pilots by the green lens at the back of their revolving searchlights. Even in thick weather these signal lights can be seen by the pilot, though he be many miles away.

Contributing greatly to the record of safety achieved by the airlines is the *radio range,* a form of communication which marks for the pilot the "roadway" in the sky just as clearly as the roads on which we drive our automobiles are marked by signposts.

It is easy to understand the working of the radio range, or *beam,* as it is commonly called. A pilot taking off from New York for Chicago, for example, turns a knob on the instrument panel which turns on a radio set that is tuned to the radio station at the airport. This station, and all the others on the route to Chicago, keep sending code messages to the pilot to keep him on the course. Notice the diagram below:

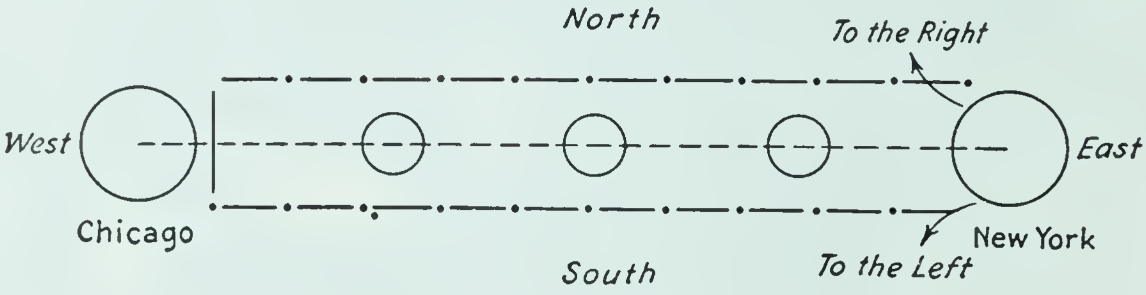


Fig. 14

The circle at the east represents the radio station at the New York airport, from which the plane takes off. The circle at the other end represents Chicago. The smaller circles between indicate the intervening radio stations flown over by the pilot.

As the plane travels on its course the radio signals sent out by the stations make a steady humming noise in the earphones of the pilot. This steady hum tells the pilot that he is on the course to Chicago—"on the beam." Should his plane turn off to the right of the course, the pilot would cease to hear the humming noise; instead he would hear this signal: dot-dash, dot-dash, dot-dash. He might as well be hearing the words, "You're flying to the right of the course." He has only to guide the plane to the left until he comes again upon the radio beam. If his plane should veer to the left of the course, the signal would be dash-dot, dash-dot, dash-dot—a reverse of the other signal.

As the plane flies on its course it passes at intervals over "check points." The beam there changes to a signal which enables the pilot to learn his exact location. He reports this position over his radio to the airport radio station.

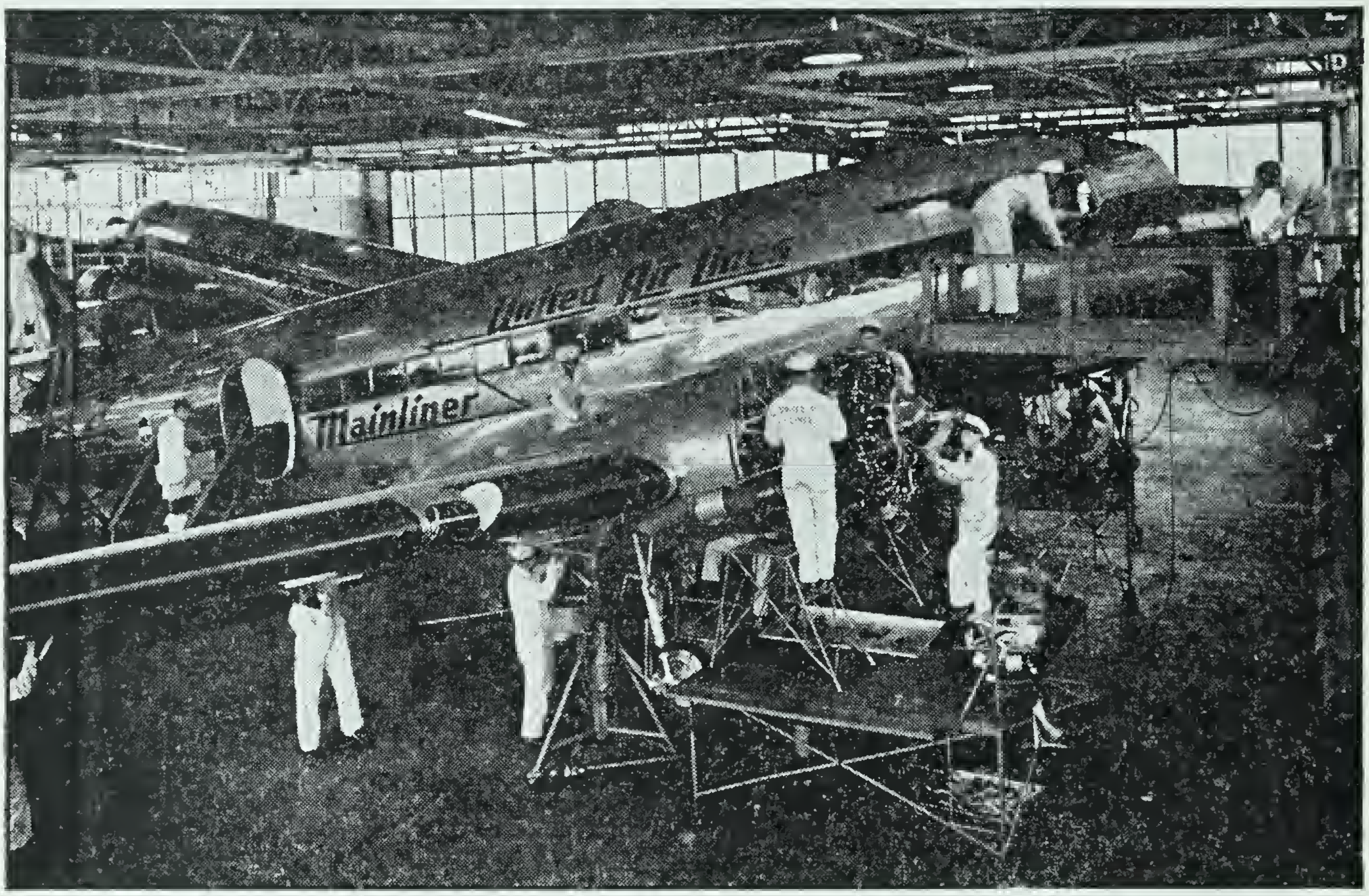
Airliner maintenance. Air transportation is a business, not a game. As a business, it is organized, systematized, and strictly disciplined. The result is a thriving, uniformly excellent mode of travel. Almost one and one-half billion passenger miles were flown by the airliners of the United States in 1941, and more than four million passengers took advantage of the speed and safety of air travel.

The average air traveler today takes the superlative performance of the airlines much for granted. As he speeds from coast to coast, for business or for pleasure, he is not usually aware of the part that maintenance mechanics have played in seeing that the luxurious liner in which he is riding is safe and that its engines are dependable. He doesn't know that maintenance mechanics are among the most painstaking and critical men in the world. Their vigilance in plane inspection and repair to make air transportation safe is not headline news to him.

To become properly air-minded, one needs to gain some appreciation of what goes on in an airline repair shop when a ship is brought in for overhaul. So let us watch the mechanics and inspectors go to work on a glittering 12-ton coast-to-coaster as it is pulled into the overhaul shop after 625 hours of flying. You will agree that plane overhaul is somewhat different from automobile overhaul.

As the nose of the liner comes to rest at a certain spot in the hangar things begin to happen. Men, young and old, each with a Civil Aeronautics Administration license, come swarming to the job, which is scheduled to be completed in two working days. Portable steel scaffoldings higher than the ceiling of your room are hauled up on their rubber-tired wheels and locked into position alongside the motors. Worktables from overhead come swinging down to the sides of the cockpit, and cranes move into position over the motors. Before the job is finished, more than three hundred mechanics will have assisted in it.

Teamwork a feature. Every man understands from experience what his particular work in the overhaul is. Without confusion or waste motion more than twenty operations are carried on at the same time. Powerful hydraulic jacks raise the massive body, and a gang of workers loosen and carry away the undercarriage. Another group removes or swings open the inspection plates to disclose the critical internal places of wings and fuselage, where trouble might develop. The inspectors, key men of the examination, diagnose the plane as a doctor does his patient. With strong lights they examine darkened fuselage and wing interiors and scrutinize every detail. To test the condition of a wing rib to which there is no inspection opening a mechanic's stethoscope is used. This instrument is simply a small suction cup on the end of a handle. As the inspector presses the cup against the underside of the wing rib he can tell from the feel and the sound whether the rib is in a condition reliable enough to do its job of support and so contribute to the plane's safety.



Courtesy United Air Lines

Fig. 15. A Mainliner being overhauled in the maintenance base at Cheyenne, Wyoming, after 625 hours of flying. During this time, the ship has flown slightly over 115,000 miles. This distance is nearly half of that from the earth to the moon.

We gain some idea of the complexity of a plane's mechanism when we consider, aside from the plane's motors, the miles of electric wiring, the many switches, cables, controls, and instruments. All these, together with the plumbing that carries gasoline, oil, and hot water to the cabin, as well as hydraulic fluids for operating brakes and flaps, must be scrutinized during inspection. Forms listing parts of the plane to be checked are used so that none may be missed.

In the radio room specialists remove equipment which is taken to the radio laboratory for testing. Half the instruments in the cockpit are taken to the instrument shop for testing, and the remainder are tested in the plane.

While this work is taking place the interior of the cabin is being completely cleaned and renovated. The rug covering the floor is removed and the floor boards are taken up to permit inspection of the belly of the plane, where the cables and tubing run. Every square inch of the cabin's interior is scrutinized, from washroom to pilot's compartment. If any fabric or upholstery is found damaged, to the upholstery shop it goes. Even the window curtains are removed and inspected.

In the meantime, the cranes have lifted the engines free of the ship, and carburetors, magnetos, and other accessories are removed and taken to special shops, where super-specialists concentrate on them. The engines themselves are in the engine shops being completely disassembled, even though they were humming perfectly before the plane was brought in.

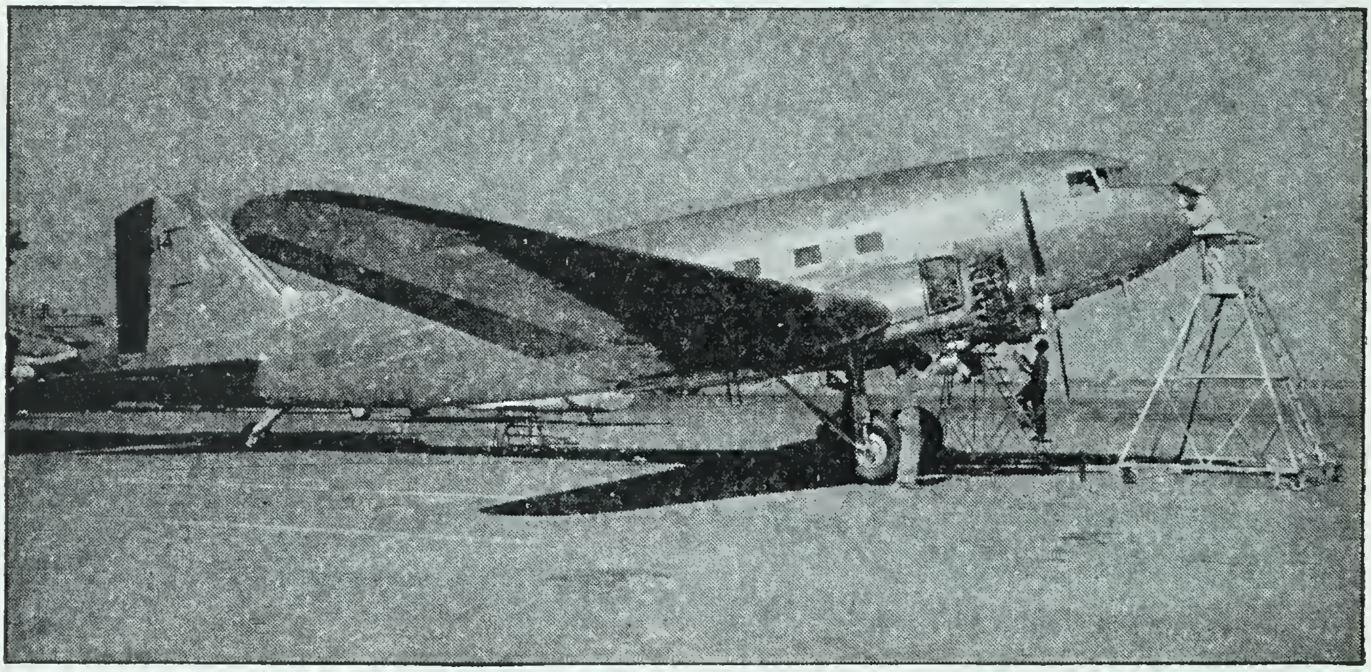
And what a disassembly! The onlooker would wonder if the motor could ever be put back together again. All bolts and nuts are removed and carefully arranged on shelves. These, together with the hundreds of other parts dismantled, are cleaned thoroughly preparatory to inspection. By a process known as *Magnafluxing* specialists are able, with the aid of microscopes and magnifying glasses, to find the smallest of surface cracks and even flaws inside the metal. Any part which does not survive this critical examination is replaced—in the name of safety and service to the flying public.

After its thorough inspection, the engine is reassembled and sent to the test room for a four-hour test run. And "test" is the word in the other shops too, where carburetors, magnetos, pumps, instruments, radios, propellers, and batteries are tested for performance under conditions that are much more exacting than those under which they will operate on the plane.

On the second workday the tide begins to turn. Approved parts, checked and cross-checked, begin to flow back for reassembly. The plane receives its fresh engines, and propellers are put into place and bolted fast. The wings again shelter in their interior the tanks that have endured a two-day sweat under high-pressure steam. The pilot's compartment gets back its instruments and radio equipment, and the belly its undercarriage, which must push down or retract in not less than 35 seconds to fulfill the rigid demands of safety inspection. The cabin gains that house-cleaned appearance which freshly laundered curtains, clean chair covers, and a vacuum-cleaned rug give. A hundred details of arrangements are cared for. The cabin is ready for the skies again—and you.

The outside of the plane is by no means neglected. Cleaners work on it until it glistens like silver. The scratches that flying pebbles may have made on the painted insignia are retouched, and windows are washed sparklingly clean.

After one more round of inspections, in which the inspectors examine their worksheets to be certain that all directed work has been done, the ship is placed in the hands of a test pilot, who flies the ship for one hour, checking every instrument and every control to make sure it performs properly. Whether the plane is ready for flight again depends on the O.K. of this pilot.



Courtesy Douglas Aircraft

Fig. 16. Safety is the watchword of air transportation. Although this plane has recently been thoroughly overhauled, it is nevertheless inspected at the end of every trip. These mechanics are making a trip inspection.

"Are planes checked only after every 625 hours of flight?" you ask. No. As a matter of fact, a ship undergoes inspection at the end of every trip. If any operating part is discovered to be only a shade out of line, it is reported and repaired before the plane takes off on its next trip. In addition to the trip check, airliners undergo a 25-hour check, a 100-hour check, the 625-hour check, which has been described, and a 5000-hour major plane overhaul. Every care is taken to insure the safety of flight.

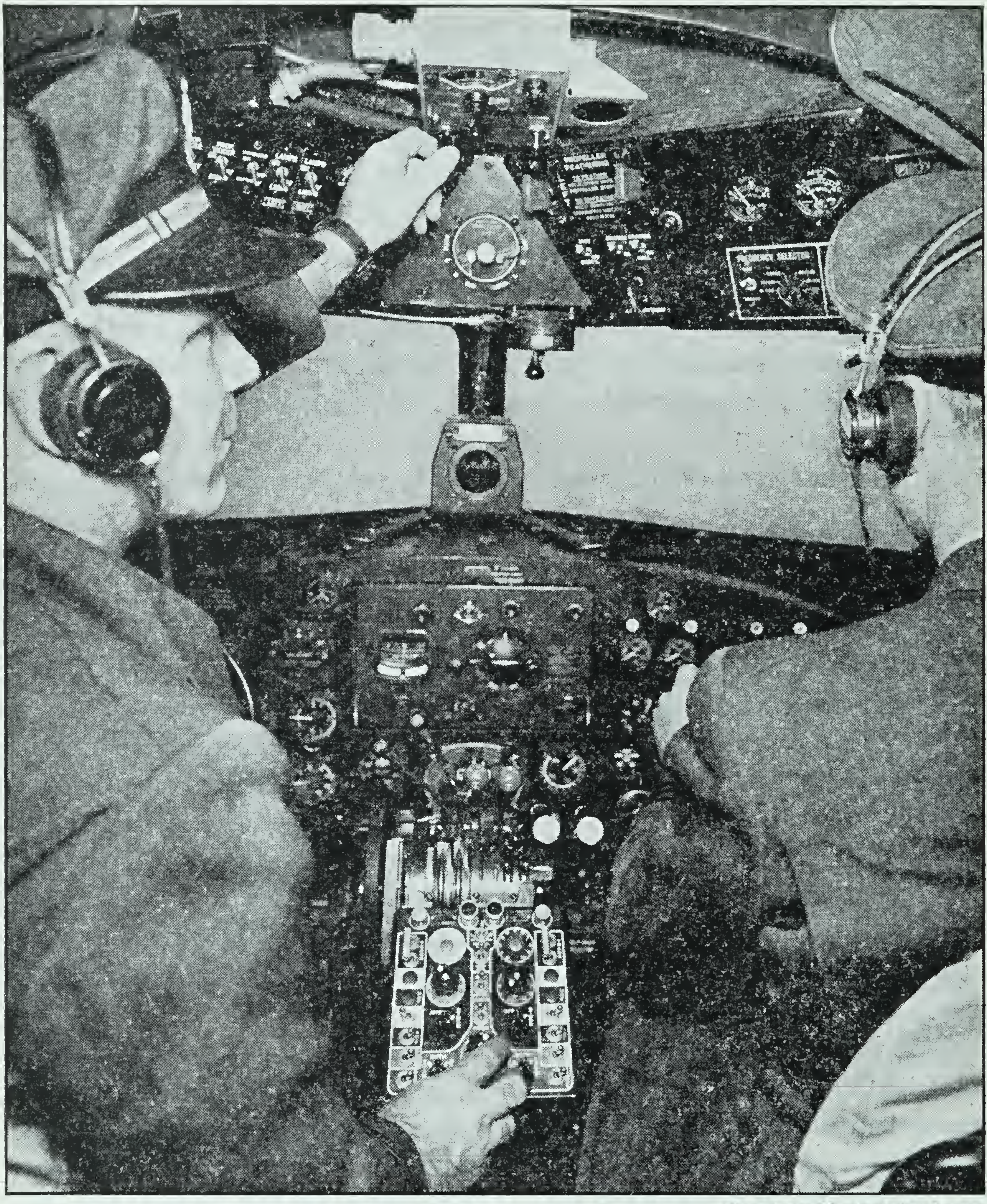
The men who run the plane. Skeptics of air travel by passenger plane may say: "Well, the machine is safe, but how about the pilot and the co-pilot who run it?"

Airlines do not gamble as to the kind of men they choose for such responsible positions as pilot and co-pilot. They demand and get in their piloting personnel the highest standard of personal and professional perfection attainable. Only to men of such caliber will they entrust expensive passenger planes and the priceless human cargoes they carry.

Just what kind of man does it take to get the job of piloting one of these big twenty-one-passenger coast-to-coast planes? What personal qualifications and experience must he have? These are pertinent questions not only to young men who want to become transport pilots but also to the general public which wishes to become intelligently informed as to how air travel is made safe through the selection of capable personnel.

Let us say at the beginning that no aviator becomes an airline pilot overnight. Many intermediate steps must first be taken. Airlines today never hire first pilots as such, no matter how excellent their flying record has been or how many fine personal qualities they may possess. Instead they hire co-pilots, train them further, check closely their abilities, and give them additional experience. If in their service as co-pilots the applicants prove their merit, they are considered for promotion to the status of first pilots.

The co-pilot. The co-pilot who assists the first pilot in the pilot's compartment of the plane on which you are depending for safe transportation to some point in the United States has met the exceedingly high standards of the airline company which employs him. He has, first of all, at least 500 hours of experience in solo flying—solo flying that was not just flying around the pleasant countryside in broad daylight but cross-country flying in weather you would not drive your automobile in. He has flown at night when the weather was so "soupy" he could hardly see the beacons. He has flown in weather which did not permit his senses to guide him but forced him to depend almost solely on instruments. He has put his ship through acrobatics that demanded the keenest of judgment and control. And he has done this flying skillfully, with a minimum of mishap.



Courtesy United Air Lines

Fig. 17. The pilot's compartment of an airliner. The Captain sits on the left side, in the picture; the First Officer on the right. Notice the earphones through which the pilots hear signals of the directional radio beam, late weather reports, and company messages. The more essential instruments are duplicated to provide an added check for safe plane travel.

Physically your co-pilot is as nearly as possible a perfect specimen of manhood. He is between the ages of twenty-three and thirty-three, an American citizen, with no serious physical defects. His heart, lungs, and all internal organs function perfectly. His eyesight and hearing are normal. His muscular co-ordination, sensory reactions, as well as emotional balance, are excellent. He is not the type to become panicky in a pinch.

Your assurance of the co-pilot's fine physical condition is the frequent physical examinations he is compelled to take under the airline's physician. Not only must he be healthy at the time of an examination but his condition must also indicate that he is likely to continue to be healthy for months to come.

Probably your co-pilot has been trained in the Army, Navy, or Marine flying service. Most co-pilots have been so trained. It has been estimated that the Government may spend as much as $35,000 to train one pilot. Aside from learning to fly, the co-pilot has been technically trained. He is a combination mechanic, radio operator, engineer, meteorologist, and navigator.

This servant of yours on the airliner learns thoroughly the routes over which he flies. He knows the location of radio-range stations, beacon lights, emergency landing fields, and other landmarks. Before he stepped into the cockpit of the plane in which you are riding, he went to the flight dispatch office with the first pilot and with the expertly trained Government-licensed officials there studied the weather and winds at various flight levels on your route and worked out the details of the flight plan.

So much for the co-pilot. Only those who are alert, eager to learn, and hard-working are finally promoted to the position of first pilot. Their apprenticeship as co-pilot to the pilot usually lasts about three years.

The first pilot. The first pilot is captain of the ship in which you are traveling. He is in full command. Once he too was a co-pilot such as the one described. At that time he did not necessarily have to hold an air-transport license, but now such a license is his authorization from the Government to be your "air chauffeur." The license means, among other things, that the holder has at least 1200 hours of solo flying to his credit and that he has passed many difficult flying tests and demonstrated a thorough knowledge of advanced navigation, meteorology, and flight technique.

Your pilot has intelligence of a high degree. He is a skillful technician in handling the plane. Month after month he maintains excellent physical condition and trigger-quick co-ordination between hands, eyes, ears, and brain. He is that "one out of a thousand" selected by airline officials to pilot your plane so that air transportation will be safe for you.

And apparently he, together with the other excellently trained employees of the airlines, is succeeding in making passenger travel by air safe. The recent action of fifteen insurance companies in removing the premium on policies issued to air travelers bespeaks the safety and dependability of air transportation.

To make the skyways safe. You are not without your faithful guardian Uncle Sam either when flying in a privately owned plane around the local airport or when traveling on a transport high above the clouds hundreds of miles from home. To help make flying safe for you and me the Government, aside from insisting that all pilots be licensed, has established rules and regulations for air traffic which are designed to make the skyways safe, just as automobile traffic rules are planned to make highways safe. To execute and enforce the rules the Government maintains a corps of expert inspectors responsible to the Civil Aeronautics Administration, whose duty it is to inspect aircraft for airworthiness, examine the qualifications of pilots and mechanics, and report air-traffic violations. Airplanes using civil airways are subject to more control from the ground than are railroad trains operating on ground-laid tracks.

You have already become familiar with ways in which air traffic is controlled at airports and with the devices used along federally marked airways to promote safe plane travel. Let us now consider some of the processes of flight in the light of what law and order do to make them safer.

Taking off and landing. The informed air traveler seldom has any fear of the plane's meeting with an accident while taking off or landing at the airport, even though he realizes the great traffic existing at many fields. Air traffic control stations are established at all principal airports along federal airways. These stations maintain stop-and-go systems which regulate the approaches, landings, and take-offs of all planes. The Civil Aeronautics Administration requires the operators of control stations to be federally licensed, thus insuring the selection of competent personnel.

All pilots know that they are required under penalty of law to obey the directions they receive from the Airway Traffic Control for taking off and landing. In their obedience they prevent confusion and danger, and protect you, the passenger.

Here are a few of the rules which govern the procedure of taking off and landing at airports, including the small local fields where no elaborate control stations are maintained:

1. Aircraft shall observe the local airfield traffic rules.

2. A take-off shall not be begun when there is danger of collision with other aircraft during such take-off.

3. Aircraft approaching for a landing shall circle the airport (to the left) unless otherwise directed, sufficiently to observe other traffic.

Pilots realize that breaking the air rules is unethical and not sensible. If they disobey the rules, they incur a scolding, a suspension of flying license, a fine, or even a more severe penalty, depending on the nature of the offense. The conditions are similar to those you face if you misbehave with your car on the highway.

Aircraft in flight—right-of-way. How many have been the fatal accidents resulting from dispute or ignorance of the right-of-way on an automobile highway! Here are some of the rules which good pilots follow so that other pilots will know what to expect of them in the matter of air right-of-way:

1. When two aircraft are approaching head-on, or approximately so, and there is danger of collision, each shall alter its course to the *right* so that they will pass each other at a distance of at least 500 feet.

2. An overtaken aircraft shall have right-of-way, and the overtaking aircraft shall keep clear of the overtaken aircraft by altering its own course to the *right*.

3. When two aircraft are on crossing courses at approximately the same altitude, the *aircraft which has the other on its left shall have the right-of-way* and the other shall give way.

4. An aircraft landing in the method prescribed by law shall have right-of-way over other aircraft in flight or on the ground or water, except aircraft in distress.

The average pilot is possessed of a great deal of common sense. Even though he may have the right-of-way over another plane, he realizes that the other pilot may not see him. Like the sensible automobile driver, the pilot knows that he can be killed maintaining his right-of-way. He therefore lays down for himself a wise rule: *The other pilot always has the right-of-way.*

Through regulations airplanes on the regular passenger airways are kept separated by at least one-third mile vertically, two miles from side to side, and forty miles from front to rear. Can you see the reason behind such a ruling? Of course, it is to prevent any collision of aircraft. Considering the speed at which planes travel, the ruling is a wise one. If, when you are traveling on an air highway, you are worried about a head-on collision or a locking of wings with another plane, visualize what this air traffic rule is doing for you and you will be more likely to enjoy your trip. Your plane has a much freer road than does your automobile.

Minimum safe altitudes. The next time you are walking down the main business section of your city and see an airplane flying over, notice the height at which it is flying. Is it at least 1000 feet? It should be, for that is the minimum height prescribed by law for aircraft flying over congested areas in cities and towns. The regulations require a safe altitude, so that the pilot, if his engine should fail, may have enough height to permit him to glide to an open space.

Aircraft are required to have a minimum of 1500 feet altitude while flying directly over an airport. While flying over land—farmsteads, country schoolhouses, and so on—they must observe an altitude of at least 500 feet.

These things shall not be done. We know you have thought of this more than once when a plane has flown directly over you: "What if the pilot should drop a flatiron or something? I'd be a 'goner' for sure if it hit me."

The laws steps in again to protect you, even though this time you are a pedestrian. Nothing shall be dropped from an aircraft in flight other than sand, fine shot, fuel, or water.

The law further forbids the carrying of explosives, arms, or munitions of war in civilian aircraft. Exceptions to the rule are arms for hunting and explosives for signals and flares.

Here is an important "It shall not be done": No person under the influence of liquor, cocaine, or other habit-forming drug (except a medical patient, or in case of emergency) may be carried in any aircraft. This rule applies to pilots, crew members, and passengers. Can you think of some reasons for this regulation?

Aircraft registration. The Civil Aeronautics Administration, in addition to promoting safety in the skyways by instituting and enforcing traffic regulations, further safeguards air travel by subjecting all airplanes to Government registration and periodic inspection.

Registration of planes enables the Government to keep tab on every airplane in the land and to check upon its airworthiness. Is the plane in which you ride fit to fly? The Civil Aeronautics Administration sees that it is by requiring an inspection of all certificated planes at reasonable intervals. If a plane passes inspection, that is, if it is safe to fly, the owner is issued an airworthiness certificate certifying that fact. If a plane does not pass inspection, it is confined by law to the ground until such time as repair enables it to meet the approval of the inspector.

We have dealt with the matter of air-traffic control rather briefly, our purpose being simply to assure you that air transportation is not free from governmental regulation but is, on the contrary, strictly and constantly supervised in the interest of both the industry and the public.

Exercise 17. Your teacher will arrange that someone in authority speak to your class on how air travel is made safe by civil air regulations. Be prepared to ask your visitor questions about rules and regulations governing aircraft operation.

Exercise 18. Work in committees or individually to read and later report to the class on the various sections of information found in Civil Aeronautics Bulletin No. 29. Pilots' Radio Manual, published by the Government Printing Office, Washington, D. C. Reports should be made on such topics as radio range stations, radio marker stations, the radio beam, and teletype service.

Exercise 19. In 1926 of a total of 8252 airway miles 2041 were lighted. In 1929 of a total of 24,864 airway miles 12,448 were lighted. In 1934 of a total of 28,084 airway miles 19,081 were lighted. In 1941 of a total of 43,217 airway miles 32,487 were lighted.

a. What effect, do you think, would this increase in the number of air miles lighted have on the safety in flying?

b. Using the above data, show by a graph the growth in the number of airway miles lighted.

Exercise 20. In 1929 there were 2415 airway miles provided with teletype weather reporting. In 1934 there were 11,631 airway miles provided with teletype weather reporting. In 1937 there were 20,588 airway miles provided with teletype weather reporting. In 1941 there were 29,422 airway miles provided with teletype weather reporting.

a. What percentage of the total airway mileage, 43,217, was lighted in 1941?

b. What percentage of the total airway mileage was provided with teletype weather reporting in 1941?

c. Using the above data, show by a graph the growth in the number of airway miles serviced by teletype weather reporting.

Exercise 21. Interview local airplane pilots on the following topics:

a. How the instruments on a plane contribute to safety in flight.

b. How a cross-country flight is planned.

c. How a pilot finds his way about.

Exercise 22. If there is an airway weather reporting station in your locality, your teacher will, if possible, arrange for the class to visit it. Work in committees beforehand to prepare questions for your visit.

Exercise 23. Consult a local travel-insurance company to find out the cost of air-travel insurance as compared with auto-travel insurance. Find out the relative safety of air travel as compared with travel by automobile or by railway train.

Exercise 24. From books, magazines, and newspapers report on readings you can find about devices and aids that contribute to making air travel safe.

Exercise 25. Find out from reading why it is necessary for airplane pilots to have such outstanding physical, mental, and moral qualifications and such thorough-going technical education and training.

Problem 4. What kinds of information must one have to become "air-conditioned"?

An interesting and tremendously important problem faces American youth today—the problem of preparing to live in an air age. Despite the sickness of war which has afflicted the world now for some time, the aviation industry has made enormous strides in recent years, changing our social and economic life, quickening our ways of doing things. That we are already living in an air age is evidenced by the great volume of air passenger travel, together with the many and varied other uses being made of the airplane: airplanes for freight and express hauling; airplanes replacing dog-team transportation in Alaska; airplanes aiding law enforcement; airplanes aiding in personal emergencies, such as sickness or lack of food in stricken areas; airplanes for service to general business, mining, construction, agriculture; airplanes for recreation. Never before has the public spotlight been centered so directly on the airplane.

It is for you high-school people to assume the future of the airplane—the irresistible expanding strength of the aviation industry. On the assumption that sooner or later this war will end and permit us to take up in full our peace-time activities, it is reasonable to believe that a not-too-faraway tomorrow will bring to us these realizations: air traffic thirty times today's volume; countless small planes designed for family use, thousands of parking fields in competition for the patronage of private pilots, large forty- to fifty-passenger-cargo transports for coast-to-coast operation; local passenger planes for intermediate city service; "flying box cars" for freight hauling; a huge expansion of airline routes for passenger travel and mail hauling.

Courtesy Transcontinental & Western Air, Inc.

Fig. 18. This mail will be speeded across the continent faster than three miles per minute.

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Certainly there will be a tremendous expansion of international air commerce. Already the airplane has reduced the size of the United States, measured in terms of time, to the size of the State of Pennsylvania. We can quite safely predict that our economic and social relations will be carried on throughout the world on the same basis as now maintained within Pennsylvania by railway and automobile transportation. Being proposed today by one of our leading aircraft companies is a sky ship designed to carry 102 passengers each with 80 pounds of baggage, plus 25,000 pounds of cargo, from New York to London in 13 hours—between breakfast and supper, we might say.

After we have won this war, much of the huge surplus of our military airplanes will be made available for commercial use. The big bombers after the enemy on the war front today will very likely be used for cargo transportation. A system of air cargo transportation offering a five- and six-hour service to every section of the nation, Canada, and Mexico will place industry at the source of many materials; factories can be built near cheap power, and airports quickly constructed to accommodate air service.

This is just a glance into the near future to reveal something of the picture which the air age, unhampered by the present job of fighting a world war, will produce for us. You, personally, will be a part of this era of the air, possibly owning and operating a plane of your own, just as your father or brothers or sisters own and drive their own automobiles today. That you may begin preparing yourselves to take your places in this world of the air age as informed and practical individuals is the purpose of this course in pre-flight aeronautics.

Let us now make something of a preview of this textbook, which is designed to air-condition you—to assist you in getting ready to do something about aviation, either as a direct participant in some phase of the industry, or as an everyday consumer whose welfare will be benefited and whose life will be fuller and richer because of an intelligent understanding of the ways and means of aviation.

Aims of this course in pre-flight aeronautics. One of the first questions asked about a new field of industry is, "What kinds of jobs are there in it?" This course will give you a good up-to-date answer to that question. In addition to giving you an insight into the many vocation possibilities of the aviation industry for men and women, the qualifications necessary to fill each job, and suggestions as to how to seek employment, it will acquaint you with the significant changes in world affairs which are being brought about by the airplane—"condition" you to the impact of the air age and what it means to us. Sometimes the full realization of things must be brought home to us before we act to do anything about them.

But perhaps the most important aim of this course is to afford you high-school students a simple, basic understanding of knowledges used in efficient aircraft operation—knowledges which must be yours if you are to play your parts well, whatever they may be, in the air age. This involves a study of the following: meteorology, aerodynamics, airplane motors, air navigation, and aircraft communications. Don't let any of these terms frighten you. Let us consider each of them for a moment to familiarize ourselves with their nature.

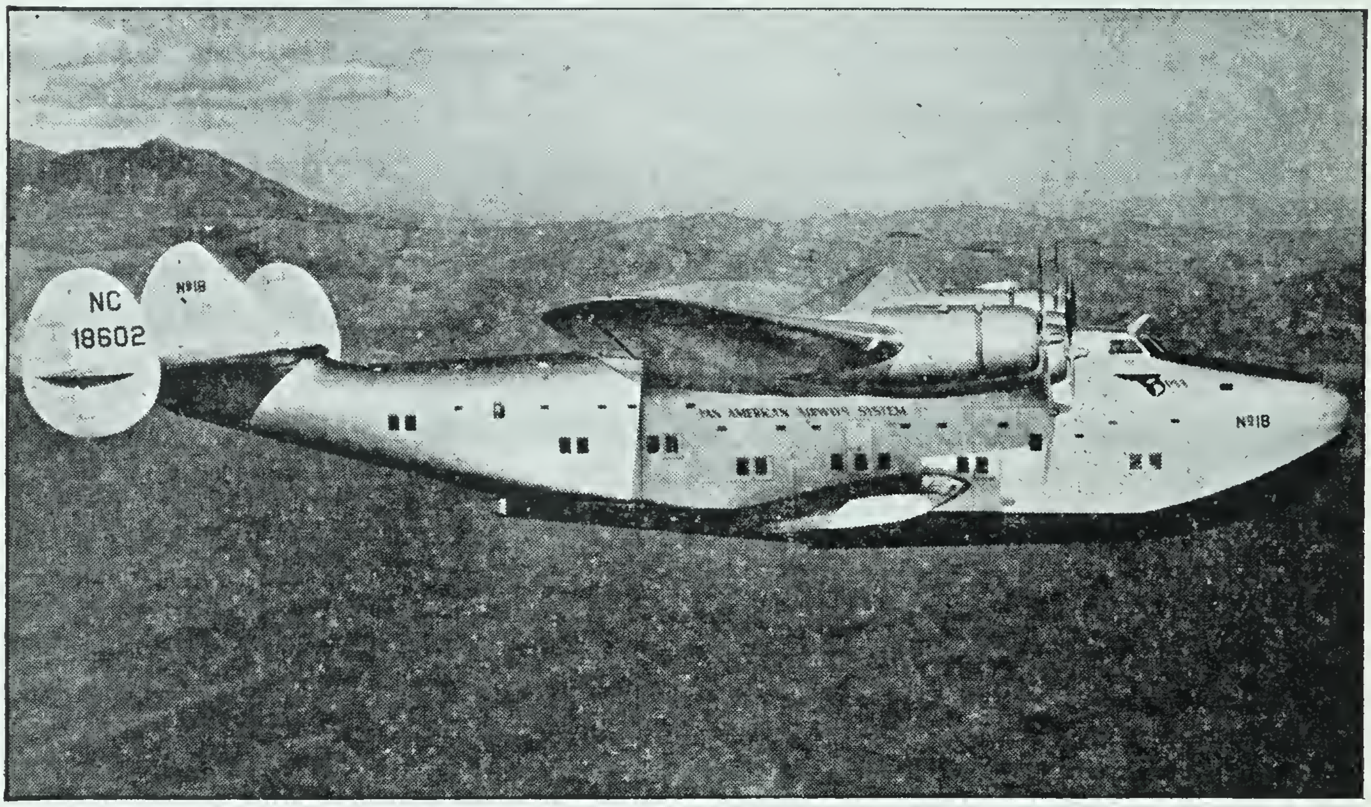
Meteorology. Meteorology is the study of the weather. Safe and efficient aircraft operation depends greatly upon this science. In the days when aviation was young, the aviator merely read the Government weather report, cocked his eye at the sky, and decided for himself whether it was safe to make his trip. Today, the pilot gets a weather prediction made especially for him and the particular route he is to fly.

As a rule, the weather is continually changing in any given locality. For the pilot who flies in a "weather factory," the changing conditions aloft are extremely important. Wind movement may carry the plane off its course; rain may freeze on the wings and cover the windshield; the plane may be carried upward or downward by strong vertical currents; clouds may cover the ground and prevent the pilot from landing.

To promote the safety and efficiency of air navigation there must be a successful solution of the weather problem. Such a solution rests upon a thorough training in meteorology. Aviation requires a dense network of surface and of upper-air observation stations manned by trained observers and the rapid transmission of reports from them; a technical staff of employees at terminal airports to prepare frequent weather maps and diagrams from which a picture of the changing weather situations may be presented; competent meteorologists to analyze current weather conditions and to issue, on the basis of these, short-period forecasts for the route to be flown.

In view of the gigantic future of air transportation thousands of high-school students will some day be employed in some phase of aviation demanding a specialized knowledge of meteorology. In this course you have an opportunity to kill two birds with one stone—gain that basic understanding of meteorology essential to anyone who would become air-conditioned and at the same time lay a good foundation for any further training you may later wish to take in the science of meteorology.

Let us proceed now to other important aspects of aircraft operation. If you are to live and participate wisely in an air age, and perhaps operate your own private plane, you will need to condition yourself quite generally to the fundamentals of aircraft operation.



Courtesy Boeing Aircraft Company

Fig. 19. One of the Boeing 314 Clippers in service on the routes of Pan American Airways. This ship has a fuel capacity of 5,400 gallons, which gives it a cruising range of more than 4,000 miles. It can carry 89 passengers.

Aerodynamics. You can gain a scientific understanding of why an airplane flies by studying aerodynamics, the fundamentals of which are simplified for you in one of the units of this textbook.

Four forces—lift, drag, thrust, and gravity—are constant companions of the pilot in the air. It is important for him to know and be able to visualize how any change of strength in each of these forces will affect the plane he is piloting. His successful piloting of the plane will depend in large measure upon how well he can control the action of these forces. Every pilot, commercial and private, needs, as a part of his training, a thorough knowledge of aerodynamics.

Highly advanced training in aerodynamics is essential to the designers of aircraft. It is they who must plan the construction of aircraft in such a manner that the sleek metal bodies of these sky ships may skim through the air with a minimum of resistance and with perfect balance.

The elementary study of aerodynamics awaiting you in this course is another phase of aeronautical information which you need to acquire in becoming air-conditioned, even though it be solely for the development of a cultural attitude toward aviation. Certainly it would be a detraction for anyone living in an air age not to have a reasonably good understanding of how the forces of the air act upon the airplane in flight.

Airplane motors. Transoceanic airliners reducing far-flung continents to a neighborhood of acquainted peoples; multimotored transports speeding in a few hours from coast to coast, carrying merchandise, raw materials, mail, and human beings; single-motored planes transporting "the folks" (you among them, perhaps) to a pleasant vacation spot—these are something of the essence of the air age. And all are dependent on the airplane motor, that vital part of the plane whence comes the power to fly. It is the very heart of the airplane, of aviation, of the air age.

It is the power that drives the propeller, that obtains the forward thrust of the plane, that enables the machine to gain the speed required to get into the air and fly. Aircraft performance depends and has always depended upon the efficiency, reliability, and economy of the power plant. The remarkable advancement of aviation in recent years has gone hand in hand with the continued development and improvement of the power plant. The achievements of air transportation today would have been impossible without it.

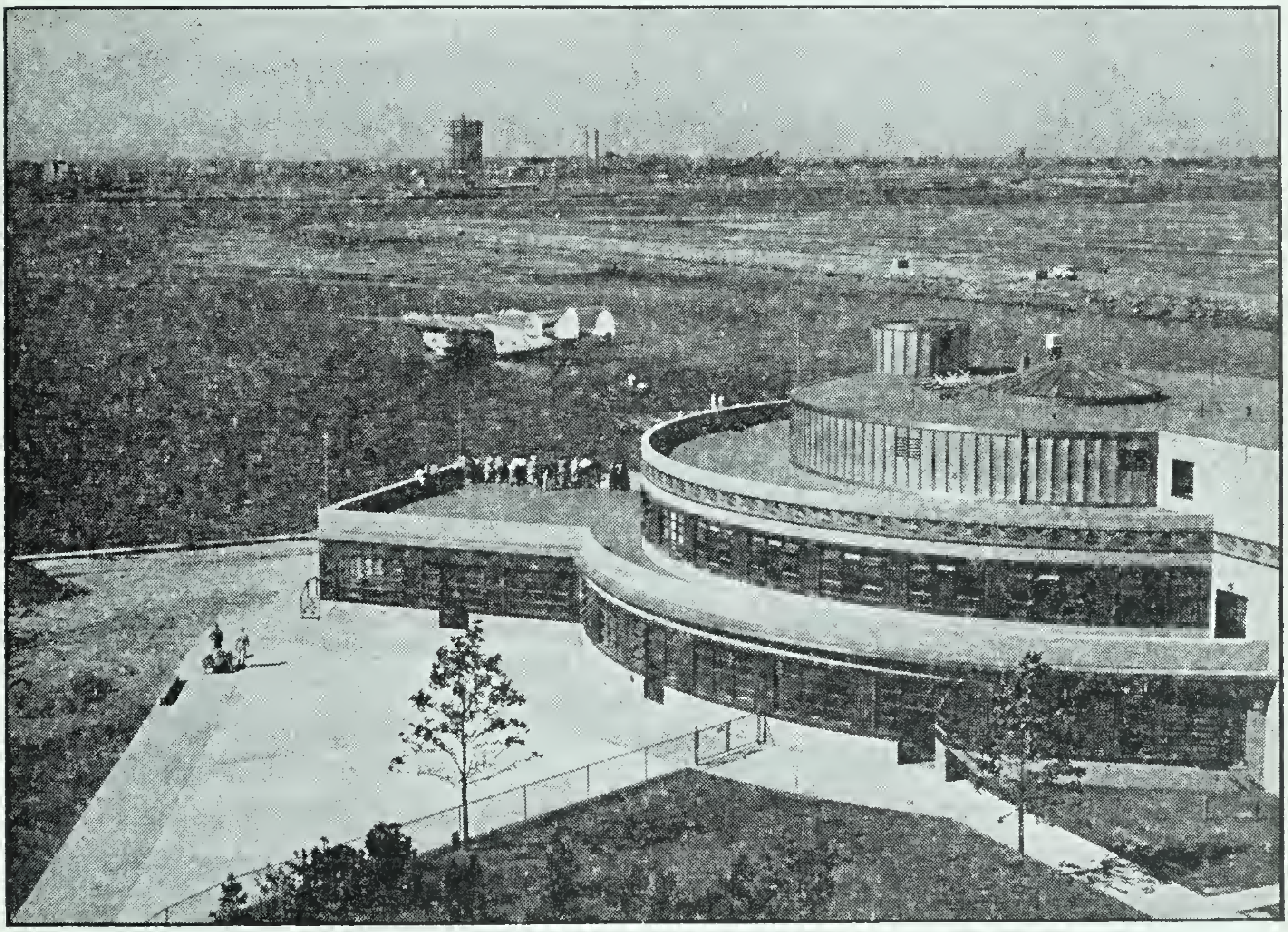
It is on the thorough understanding of the principles, construction, and operation of the airplane power plant that our future flying success rests. Today the call goes out to you high-school students to condition yourselves to fit into that great body of pilots, engineers, and mechanics who keep the ships in the air and work toward a still better performance of aircraft. After high school many of you will take specialized training as pilots, maintenance workers, or engineers. You can break ground for such training now by a conscientious study of airplane motors, as presented in this course. If your particular niche in the air age is in some other field of activity, you will still need a fundamental understanding of airplane motors in order to be air-conditioned—well-informed workers in the business of aviation, enlightened citizens in an air age. Anything that has become so overwhelmingly significant and important in our world as the airplane motor deserves intelligent consideration and understanding from all of us.

Courtesy Pan American Airways

Fig. 20. Steward in the galley of a transoceanic clipper

Air navigation. Learning to fly an airplane, if only for the sake of learning to fly, is well worth while. But if the airplane is to be used expeditiously in flying from one place to another, the ability to direct the aircraft to desired locations must be acquired. We may learn to drive an automobile—that is simple enough. But using our automobile to transport us from home to a point at some distance, for example, requires, in addition to operating the vehicle, the ability to find our way to the point of destination. We must be able, therefore, to read road maps and highway traffic signs intelligently and to use good judgment in the selection of routes to travel.

The directing of aircraft from one place to another is the science of air navigation. A fundamental knowledge of this science is essential to air-conditioning, regardless of how directly or indirectly we may participate in the air age. Just as we need a knowledge of other essentials of aircraft operation in order to be intelligently informed about the world around us, so we need an understanding of how the pilot, cutting across all barriers and surface limitations, deserts, mountains, and oceans, expeditiously finds his way about to fulfill safely, speedily, and economically the demands of air transportation.



Courtesy Pan American Airways

Fig. 21. Clipper ship at the Marine Base of La Guardia Field

In the simplified and easily understood treatment which this textbook gives the science of air navigation, you may come to learn of the four methods used in directing aircraft from one point to another;

namely, piloting, radio navigation, dead reckoning, and celestial navigation.

How maps and charts aid the aviator, how instruments are used in air navigation, how an aviator uses dead reckoning, how the log of a cross-country flight is made—these are some of the things you will have an opportunity to learn in this course. Those of you who are definitely planning to become pilots, those of you who may become pilots, remember your training period will be materially shortened by mastering the fundamentals of air navigation while you are in high school. Begin to prepare yourself now.

And do not forget that at least an elementary understanding of air navigation is a part of the aeronautical knowledge which all of us must have to become properly air-conditioned, even though we do not so much as "get one foot in the air," or participate directly in any aviation activity. After all, some of these days a large part of our food will be air-transported; many of our clothes will be sent to us by plane; a host of our neighbors will be working in some field of aviation. Our very daily existence will be permeated with the essence of the air age. The airplane will be as common a vehicle of transportation as the automobile is today. The best use will be made of it if the public generally has a reasonable understanding of its operation.

Aircraft communications. The cowboy, pausing to let his pony graze on the prairie grass, may hear only the droning motors of an airliner as it flies, cloud-hidden, at triple express-train speed over the western plains. The puncher might be prone to say, "I thought I was alone and far away from things, but that plane *really is* alone." No, Mr. Cowboy, the plane may seem to be isolated but, as a matter of fact, it is virtually "tied to the apronstrings" of Mother Control on the ground.

The engineer of a locomotive must depend almost entirely upon the signals he receives from lights and semaphores and upon any information he may receive at scheduled station stops. But the air pilot is able to hear the directing voice of the airline dispatcher from the time he takes off at one airport to the time he taxis to a landing at another. Moreover, he is actually able to hold conversation with directing personnel on the ground.

The excellent safety record of airline transportation is in large measure due to the marvels of aircraft communications, particularly the seeming magic of radio. In one part of this textbook you will learn of the ways in which radio is used in air navigation. Another section of the textbook supplements this information by giving you, among other things, an understanding of the mechanical and electrical principles involved in radio and the specialized procedures and code signals employed for airport traffic control. The seeming wonders of aircraft communications are laid bare to you in a simple, understandable way, setting the stage for more advanced training you may wish to take in this important area of the aviation industry.

So there you boys and girls have it—a brief preview of this course in pre-flight aeronautics. You have the materials to do with what you will. If the airplane helps us to have a better world tomorrow, it will be because of your wise planning and earnest effort to contribute your best in whatever capacity is yours. Start now to consider yourself a part of the air age. Start now to prepare yourself to live usefully and well in it. This course, under the direction of your teachers, will help you do it.

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UNIT II

THE OCEAN OF AIR

Exploratory Activities

1. What do you think an aviator should know about the weather?
2. Where can an aviator obtain accurate information about the weather?
3. What part do scientific instruments play in the gathering of important weather information?
4. Why is it that newspapers do not publish a daily weather map when the nation is at war?
5. Do you think that the United States Government or the airlines should furnish weather information to pilots? Why?

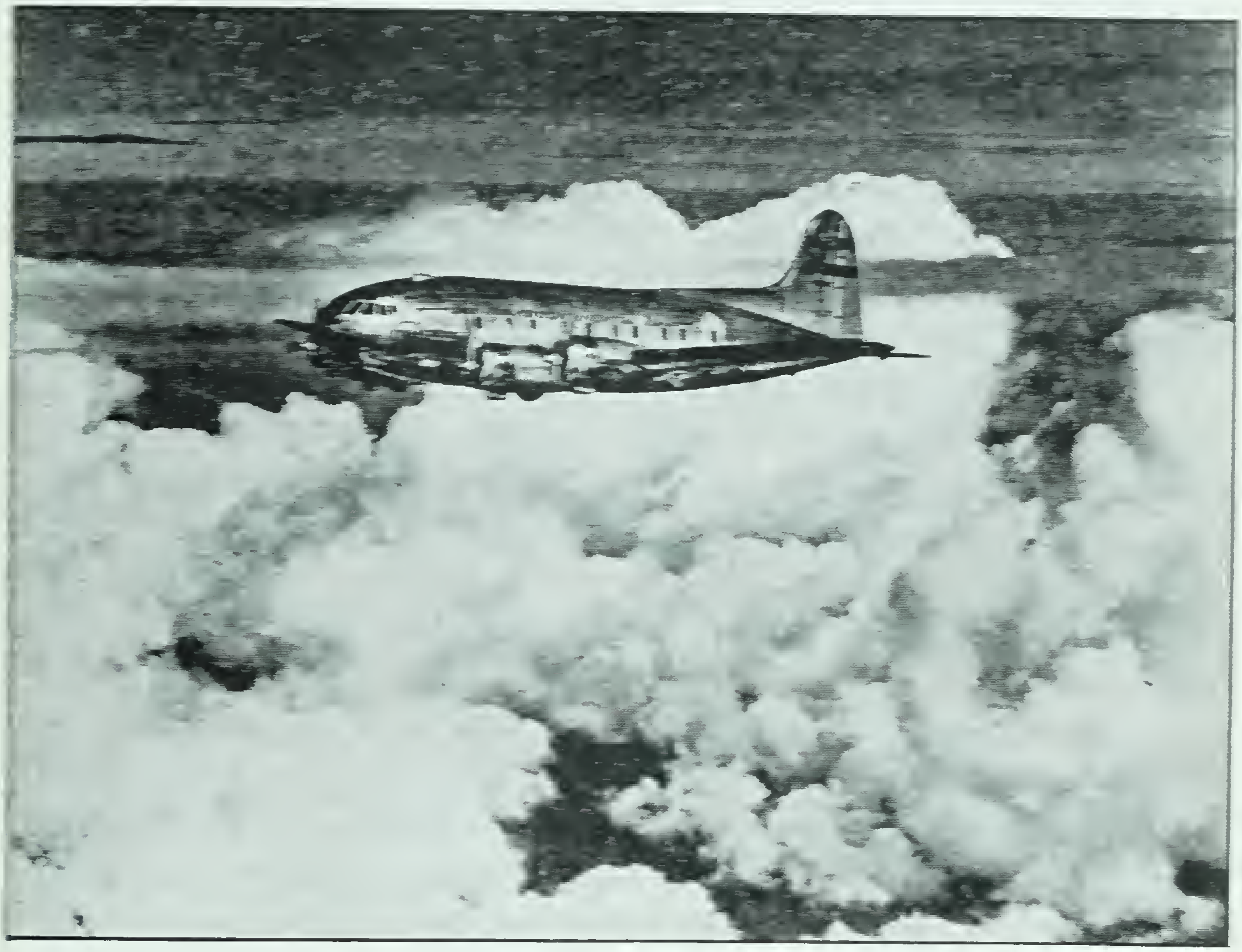
Overview

This unit presents a simplified scientific interpretation of weather phenomena. It sets forth the facts and principles of the behavior of weather which every air traveler needs.

Up until very recent times men were concerned mainly with the horizontal movements of the air, especially with those close to the earth's surface. With the advent of the airplane it was necessary to study scientifically the vertical movements of the air as well as its horizontal movements. Upper air observations which are now being made are furnishing the air traveler with additional weather information which can be used to plan a successful journey.

It is only recently that the President, by executive order, placed the United States Weather Bureau in the Department of Commerce. This agency now issues a weather map which presents the kind of information on weather that the aviator needs. In addition, commercial airlines have established their own weather stations which work in close co-operation with the United States Weather Bureau.

This presentation explores the many characteristics of *the ocean* *of air.* It is hoped that the experience gained by the student in a study of this unit will prepare him to observe and interpret the daily weather, to read the daily weather map, and to make proper use of weather reports given over the radio and in the daily newspapers.



Courtesy Transcontinental and Western Air, Inc.

Fig. 22. The flight plan which the pilot of this Stratoliner received before he took off from the airport indicated that he would need to fly at an altitude of 18,000 feet in order to be above the altocumulus clouds.

Problem 1. What should an individual interested in flying know about the ocean of air?

Air essential to life. Air is essential to life. It would be impossible, indeed, for human beings to live on this earth if it were not for the air, because, even though they cannot see it, they breathe it and depend on it to evaporate excessive moisture from their bodies, to bring moisture to the crops or to move the clouds across the sky, to dry the highways and airport lanes, and now to carry on its back their planes for business or for pleasure.

What is the air like through which the plane flies? What are its characteristics? Is it the same near the earth's surface as it is at higher elevations? These are the questions that will be answered in a treatment of this problem.

What air is. Air is a real substance, mostly a mixture of gases. It is just as real as the birds that fly through it, the earth on which we live, or the grass that grows. It has no limitation of space imposed on it as have the oceans of water, but extends its bulky mass high into the upper regions and fades away imperceptibly into space. Because it is a substance, there are certain laws which govern its activity. The aviator needs to understand these laws.

Dry air, that is, air without dust or water vapor, is predominantly nitrogen. In fact, nitrogen composes about 78 per cent of its volume. Oxygen, the life-giving element, makes up another 21 per cent of the air. It is life-giving to aircraft, too, since it makes possible the combustion of gases used by airplane motors. By means of the oxygen tank the aviator explores unknown regions of the upper air. Other gases which are present in air, some of them very rare, are argon, carbon dioxide, hydrogen, helium, neon, krypton, and xenon. It is generally believed that these gases are distributed in all parts of the atmosphere.

The molecules of each constituent of the air are crowded more closely together near the earth's surface because of the weight of the air above them. This results in a greater density near the earth and a gradual lessening of density at higher altitudes. In fact, the density of the air is so great near the surface of the earth that more than half of its entire mass lies below 18,000 feet, or under 3.6 miles, although some air extends to a height of well over 200 miles. Ordinarily the temperature is greatest near the earth and decreases with altitude up to about 40,000 feet.

Water vapor is always present in the air but never occupies more than 4 per cent of its total volume. It is one of the essential parts of the air because of its role in determining the variability and violence of the weather. A lack of moisture in hot air causes the skin to parch and crack. On the other hand, a large amount of moisture in the air makes one feel colder in cold weather and uncomfortably warm in hot weather. Extreme variations in either case are serious handicaps to one's health.

Dust, although not a gas, is an important constituent of the air. It consists of organic particles, such as seeds of plants, spores, and bacteria and of inorganic particles, such as fine particles of soil, volcanic ash, smoke from various sources like burning grass, forest fires, trains, automobile exhausts, and industrial cities. At higher elevations meteors add dust to the air. Dust is an essential part of the air because some kinds of dust form nuclei for the condensation of water vapor. All of these components of air directly or indirectly affect flying.

Characteristics of air. The chief characteristics of the air are: (1) its ability to move in all directions, (2) its ability to expand and exert pressure, and (3) its ability to be compressed with increased pressure.

Air movements. The atmosphere through which the plane flies is in constant motion. It moves both horizontally and vertically. This movement is related to the expansion and contraction of the air.

Boyle's Law. Air has neither definite shape nor size. It expands until it fills all the space open to it. It is impossible to have a container partially filled with air. The pressure that any given amount of air will exert depends upon its density and its temperature. If the temperature remains the same, the pressure which a given mass of air (gas) exerts is inversely proportional to its volume. This principle is known as Boyle's Law.

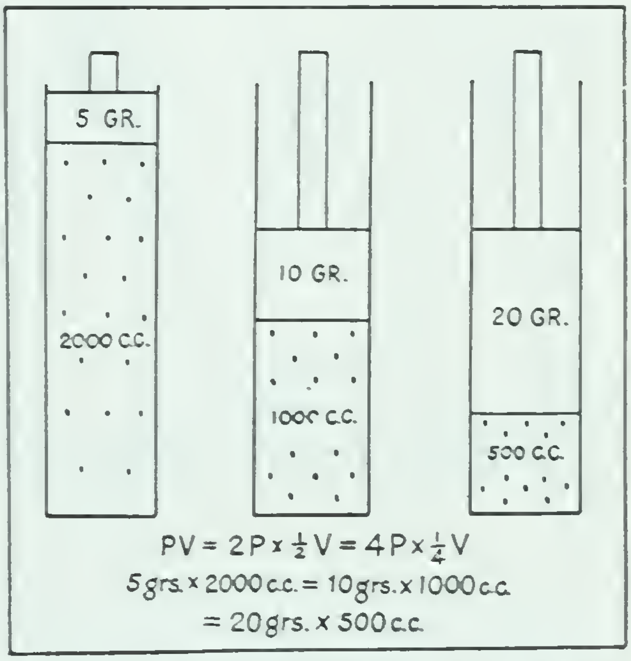


Fig. 23. A demonstration which shows the relation of pressure to volume

When air is compressed it decreases in volume and increases in density. The relationship between air pressure and air volume, assuming constant temperature, is illustrated here. In cylinder number 1 the piston weighs 5 grams and thus exerts 5 grams of pressure on the air confined in the cylinder. In cylinder number 2, where the weight of the piston has been doubled, the volume of the air has been decreased to one-half its original volume. In cylinder number 3, where the weight of the piston has been increased to 20 grams, or four times its weight in cylinder number 1, the volume of the air has been decreased to one-fourth its original volume. This principle (Boyle's Law) can be stated algebraically thus:

$$\frac{P_1}{P_2} = \frac{V_2}{V_1}$$

where P_1 and V_1 represent the original pressure and volume, respectively, and P_2 and V_2 the pressure and volume resulting from a change in conditions.

A simple experiment which shows the expansion of a given volume of air with a decrease in air pressure is as follows:

Laboratory Exercise 1.

Equipment: Pump plate, aspirator or suction pump, bell jar, small rubber balloon.

Procedure: Place a partially inflated balloon under a bell jar on a pump plate. (Be sure that no air can get in under the jar.) Pump air out of the jar. As the air pressure in the jar decreases, the air inside the balloon will enlarge the balloon. As the pressure continues to decrease, the balloon will expand and, if it does not burst, will fill the jar. This proves that air can and will occupy all the space open to it.

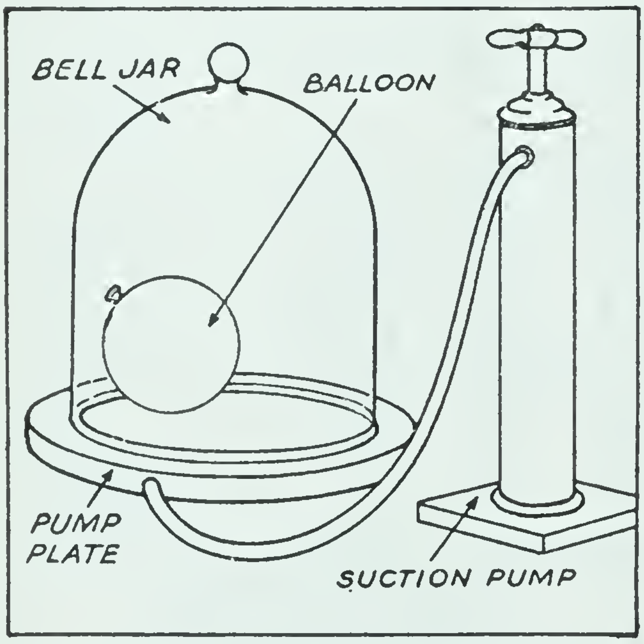


Fig. 24. An experiment which shows that air will occupy all space open to it

Exercise 2. If the original volume of a mass of air is 1000 cubic feet and if the air is under a pressure of 20 pounds per square inch, what will the volume become if its pressure is decreased 10 pounds per square inch, temperature remaining constant?

Exercise 3. If a mass of air occupies 1000 cubic feet and is subjected to a pressure of 20 pounds per square inch, what pressure change will result in increasing the volume to 10,000 cubic feet, all other factors being equal?

Exercise 4. If a mass of air has a volume of 100 cubic feet and is under a pressure of 15 pounds per square inch, what will the volume be if the pressure becomes twice as great, temperature remaining constant?

Charles' Law. Air increases or decreases in volume with an increase or decrease in temperature. This is known as Charles' Law.

Jacques Charles, a French chemist, discovered in 1787 that by keeping the volume of a specific quantity of gas (air) constant, the pressure decreased $\frac{1}{273}$ of its pressure at 0° C. for each centigrade degree of decrease in temperature. Therefore, if the temperature could be decreased to — 273° C., the pressure of the gas (air) would be reduced to zero; that is, its molecules would cease to move. He further discovered that a corresponding increase in pressure occurred as the temperature was increased.

A temperature of — 273° C. is called the *absolute zero,* because, according to this law no lower temperature can possibly exist, since neither pressure nor molecular movement can be less than zero. Absolute temperatures are temperatures measured in centigrade degrees from the absolute zero. Centigrade thermometer readings can be changed to absolute readings by using the formula, $A = C + 273$. Charles' Law may be stated algebraically thus:

$$\frac{P_2}{P_1} = \frac{T_2}{T_1} \text{ or } P_2 = \frac{T_2}{T_1} \times P_1$$

where P_1 and P_2 represent the respective pressures of the inclosed gas and T_1 and T_2 represent the corresponding absolute temperatures.

Exercise 5. If the original temperature of a mass of air is 1° C. at a pressure of 14.7 pounds per square inch, what pressure will be required to increase the temperature to 3° C., volume remaining constant?

Exercise 6. If the temperature of a mass of air is — 10° C. under a pressure of 7.5 pounds per square inch, what pressure change will increase the temperature to 3° C. if the volume occupied by the air remains the same?

Exercise 7. If the temperature of a mass of air is 7° C. and the air is under a pressure of 15.2 pounds per square inch, what will the temperature be if the pressure becomes 14 pounds per square inch and the volume remains unchanged?

Gay-Lussac Law. Joseph Louis Gay-Lussac, another French chemist, discovered in 1802 that by keeping the pressure of a gas (air) constant the gas decreased $\frac{1}{273}$ of its volume at 0° C. with each decrease in temperature of 1° C. Thus, if the temperature could be decreased to — 273° C., the volume of the gas would be reduced to zero. On the other hand, an increase in temperature, pressure remaining constant, was found to result in a corresponding fractional increase in volume for each centigrade degree of temperature increase.

Gay-Lussac's Law may be stated algebraically thus:

$$\frac{V_2}{V_1} = \frac{T_2}{T_1} \text{ or } V_2 = \frac{T_2}{T_1} \times V_1$$

where V_1 and V_2 represent the respective volumes under different temperature conditions and T_1 and T_2 the corresponding absolute temperatures.

Exercise 8. If the original volume of a mass of air is 1000 cubic feet at a temperature of 20° C., what will the volume become if its temperature is decreased to 10° C., pressure remaining constant?

Exercise 9. If a mass of air occupies 1000 cubic feet at a temperature of — 20° C., what temperature change will result in increasing the volume to 10,000 cubic feet?

Exercise 10. If a mass of air occupies 100 cubic feet at a temperature of 30° C., what will the volume be if the temperature increases to 50° C., pressure remaining constant?

Summary. Boyle, Charles, and Gay-Lussac, through careful experimentation stated the three laws which explain the relationship between the pressure, volume, and temperature of air. These laws are summarized as follows:

1. The volume of a given quantity of gas (air) is inversely proportional to the pressure, assuming constant temperature.
2. The pressure of a given quantity of gas (air) is directly proportional to the absolute temperature, assuming constant volume.
3. The volume of a given quantity of gas (air) is directly proportional to the absolute temperature, assuming constant pressure.

Law of gases combined. By combining the findings of the three scientists, Boyle, Charles, and Gay-Lussac, the relationship between pressure, volume, and absolute temperature can be expressed algebraically thus:

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

Obviously, it is possible to find the sixth factor when any five of the factors are known.

Exercise 11. If a quantity of air exerts a pressure of 15 pounds per square inch and has a volume of 2 cubic feet at — 3° C., what will the new pressure be when the volume is 4 cubic feet and the temperature is 87° C.?

Exercise 12. What would the volume of the air in exercise 11 be if the pressure were 10 pounds per square inch and the temperature 100° C.?

Exercise 13. If, in exercise 11, the volume of the air were 4 cubic feet and the temperature 270° A., what would the pressure become?

Exercise 14. If the pressure were 30 pounds per square inch in exercise 11 and the volume 2 cubic feet, what would the temperature of the air be?

A given mass of air expands as it moves upward. The air is held to the earth by gravity. The lower air is compressed by the great weight of the air above. This weight normally exerts a pressure of 14.7 pounds on each square inch of the earth's surface at sea level. The pressure on a given mass of air decreases with an increase in altitude. Consequently, a rising mass of air expands and its density decreases; the temperature of the air decreases as a result of this expansion with increase in altitude. This decrease in temperature of the air tends to increase its density. The effect of the decreased pressure, however, more than offsets the effect of the decreased temperature, and in all instances the air decreases in density with increased elevation.

Thus, air cools as it expands. When a mass of air rises, the pressure on it decreases. This decrease in pressure is accompanied by lower temperature. The decrease in temperature is about 5½ degrees Fahrenheit for each 1000 feet of elevation. Since up and down motions are continually occurring in the atmosphere up to high altitudes, the atmosphere is kept more or less stirred up vertically; consequently the temperature usually is lower and lower the higher above the earth one goes. The average decrease of temperature with height is less than the above rate at which rising air cools, however, and is only about 3½ degrees Fahrenheit per 1000 feet. Thus, the temperature of the air through which a plane flies is much lower than it is at the surface of the earth. Most large airports which experience warm weather have trucks equipped with air-conditioning units. This air-conditioning system is attached to the plane and consequently adds to the comfort of the passengers while the plane is unloading and reloading.

The three spheres. The atmosphere comprises at least three definite spheres (Fig. 25). Recent scientific research has classified the vertical cross section of the atmosphere into at least three definitely established spheres; namely, the troposphere, the stratosphere, and the ionosphere. Of this group, the *troposphere* is the best known. It in-

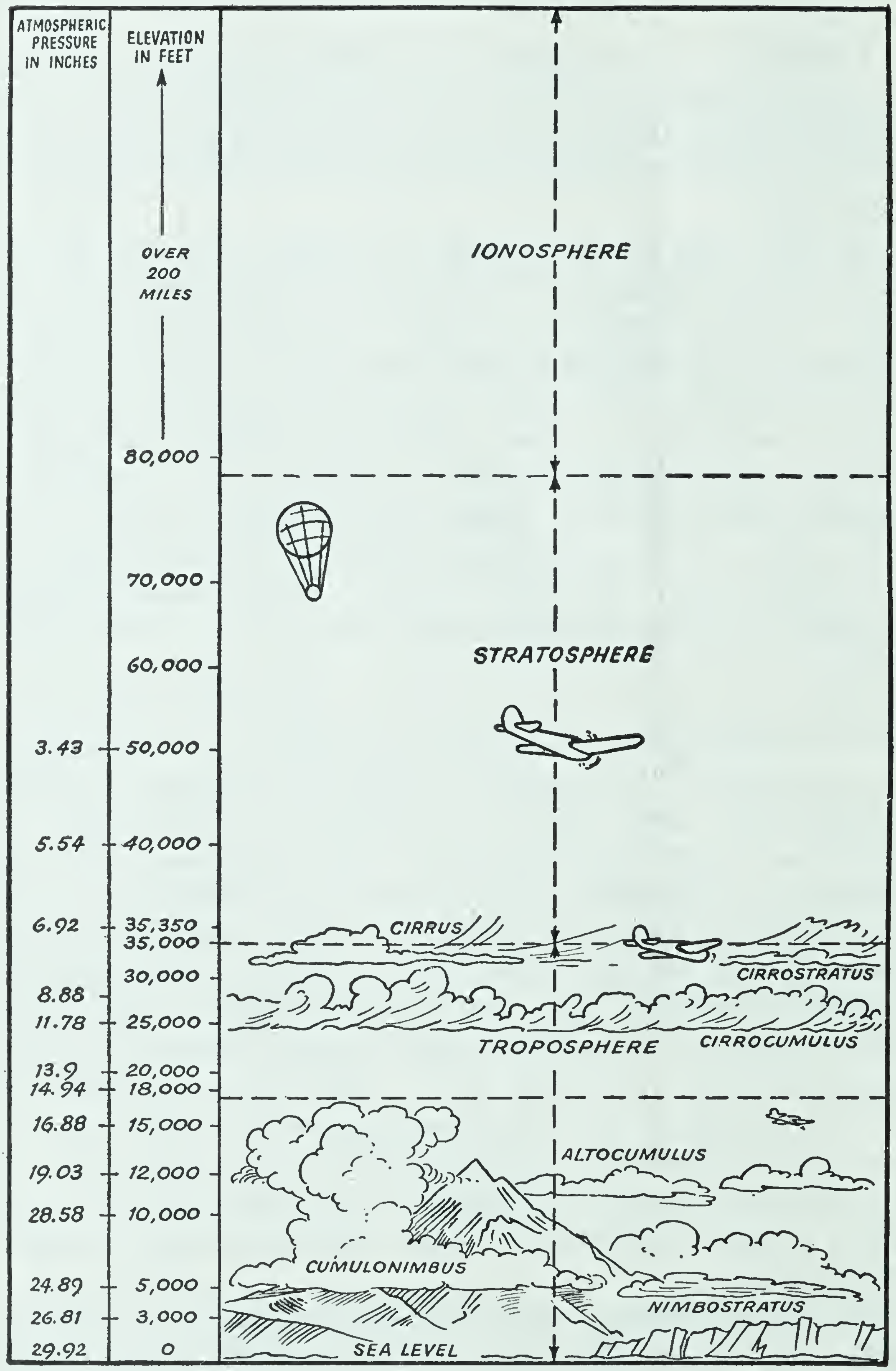


Fig. 25. Cross section of the atmosphere

cludes the air from the surface of the earth up to a height averaging 7 miles in depth in the middle latitudes, and is compressed at the bottom of the more than 200-mile-deep ocean of air. It is the region in which more than ninety per cent of the atmosphere is found and in which, until recently, man pursued all of his activities. The air here is in constant motion vertically as well as horizontally. It is the region of clouds and changing weather conditions in which the temperature and pressure drop at a rather uniform rate as the altitude increases.

The *stratosphere* rests upon the top of the troposphere and rears its rarefied mass to a lofty height of about 50 miles from the earth. It differs from the troposphere in that it is free from storms and hindering clouds, and its horizontal atmospheric patterns are unbroken by disturbing vertical disturbances. Its temperature, though about 67° F. below zero, remains almost isothermal (constant) throughout its total depth, with probably a slight increase near its upper margin. This is the region toward which aviation is looking with the hope that some day it will be alive with specially built speed planes to shorten distances between neighboring countries and to minimize the time required to cross the oceans.

The *ionosphere* is the least known. It rests upon the stratosphere and extends the atmosphere more than 200 miles into space. Recently science has found this region very essential to radio whose waves are reflected from it back to earth. It is also a region in which, although barometric pressure is at an absolute minimum, it is believed the temperature once more rises from unbearable sub-zero temperatures to temperatures perhaps equal to those on the earth.

Exercise 15. What are the properties and characteristics of the air which make flight possible?

Exercise 16. What causes the horizontal and vertical movements of the air?

Exercise 17. What did Boyle, Charles, and Gay-Lussac prove about the behavior of air?

Exercise 18. What special equipment must planes have in order to fly successfully in the stratosphere?

Exercise 19. Name and describe the chief characteristics of the air.

Exercise 20. Name and describe the three general spheres of the atmosphere.

Exercise 21. What did Boyle, Charles, and Gay-Lussac discover about the behavior of gases?

Exercise 22. Why is the government becoming more and more interested in the stratosphere?

Problem 2. What should the air traveler know about the elements of weather?

The air age. Thousands of people travel by plane every day. Haphazard forecasts and mere guesses as to what the weather will be like are no longer satisfactory. The air traveler must know what kind of weather he will encounter throughout his entire flight. Weather phenomena, fortunately, can be measured, and when they are properly recorded and related, a very satisfactory forecast can be made.

Meteorologists have been scientifically studying the weather for more than one hundred years. When they report an "observation" today it is understood throughout the entire world. This is a marvelous achievement. Such understanding is possible because instruments which record weather information and the methods of treatment of this information have become standardized. Meteorologists will never be able to forecast with one hundred per cent accuracy because of certain uncontrollable variations in the atmosphere. They do, however, forecast the weather accurately almost ninety per cent of the time.

The elements of weather, the behavior of which must be known if one is to observe and forecast intelligently, are: (1) the temperature of the air, (2) the pressure that it exerts, (3) the direction and speed of the wind, (4) the humidity of the air, (5) the amount of cloudiness, and (6) the amount of precipitation. A careful study of each one of these elements will acquaint the reader with certain basic principles and their application and with the scientific methods used in weather analysis. The air traveler with such information can forecast the weather and plan his flight accordingly.

Temperature of the air. The relation of earth and sun is such that the earth and therefore the atmosphere are heated unevenly. The variations in temperature which result account for most of the phenomena of weather. This uneven heating of the atmosphere causes winds, storms, clouds, rain, and snow, all of which are of great concern to airmen.

How is the air heated and cooled? What effect has temperature variation on the behavior of weather? These questions are answered in this section.

During the day when the sun is shining the sun's rays heat the earth and to some extent the lower atmosphere; the earth in turn loses much of its heat to the atmosphere. At night the earth and the atmosphere cool by radiation. In the daytime the air which comes in contact with the warm earth is heated mainly by the process, to be described later, known as conduction, and at night is cooled by this same process.

The sun loses its energy to the earth in a form which has many of the characteristics of waves. Though it is not possible to form a mental picture of these waves, there is a great deal of evidence that waves of energy do travel from the sun to the earth. Energy thus transferred is called *radiant energy.*

Laboratory Exercise 23.

Equipment: Two identical thermometers, two metal containers with lids (one blackened on the outside with lampblack or soot, each with hole in lid to accommodate thermometers), source of heat (the sun if possible or an electric heater).

Procedure: Place the thermometers in the cans so that their bulbs hang about midway between the lid and the bottom. Place on the window ledge if the sun is shining, or allow a Bunsen burner to burn luminously equidistant from each can. Note the thermometer readings before applying heat. (See Fig. 26, page 72.)

1. Which thermometer shows the greater amount of change? Why?
2. Was the change upward or downward? Why?
3. What method of transferring heat has been demonstrated?
4. Define this method of transferring heat.

Sun the source of heat. The heat which warms the surface of the earth and the atmosphere comes almost wholly from the sun. This solar radiation received on the earth is known among scientists as *insolation.*

Everyone knows that temperatures vary from place to place and from time to time. It is warmer, for example, during the month of January in Georgia than it is in Nebraska. It is warmer in Nebraska during July than it is in January. The temperatures at any fixed point vary with the amount of insolation (radiant energy) received.

The amount of insolation which any fixed point will receive depends upon three factors, each of which is briefly described here.

Duration of sunshine. The earth receives much less radiant energy from the sun on cloudy days than it does on clear days. Other factors being equal, the amount of insolation received is directly proportional to the length of time that the earth receives energy from the sun. In summer, when the days are long, the amount of insolation which the earth receives is greater than in winter; consequently the temperature is higher.

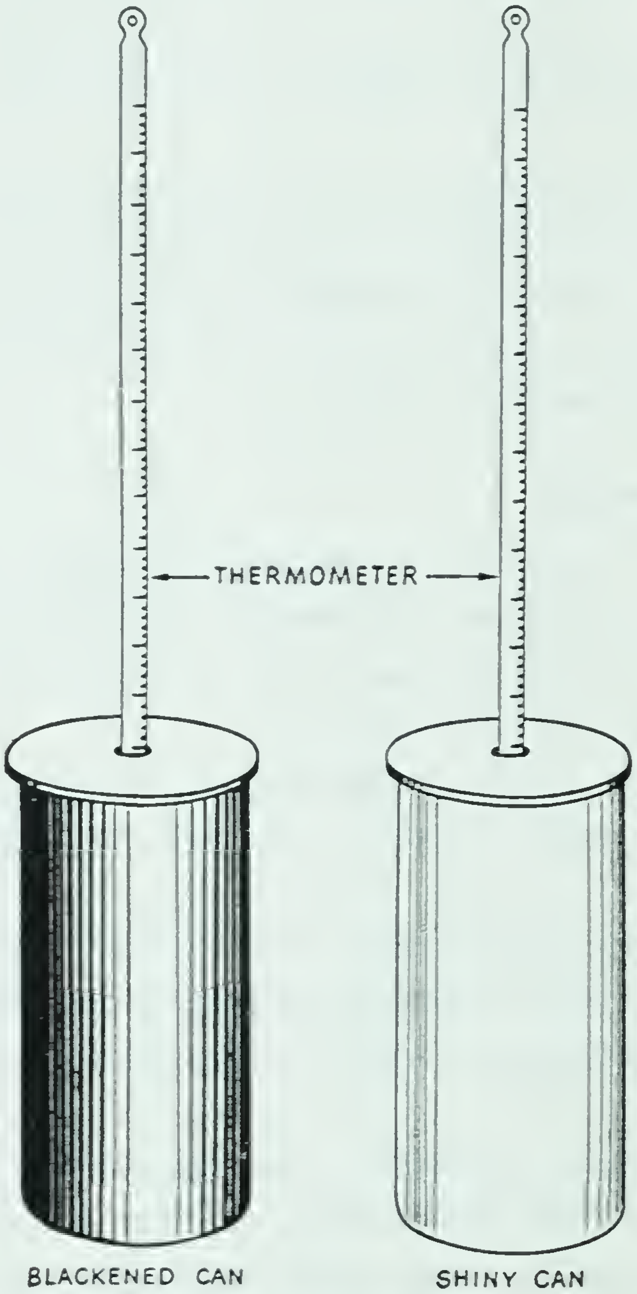
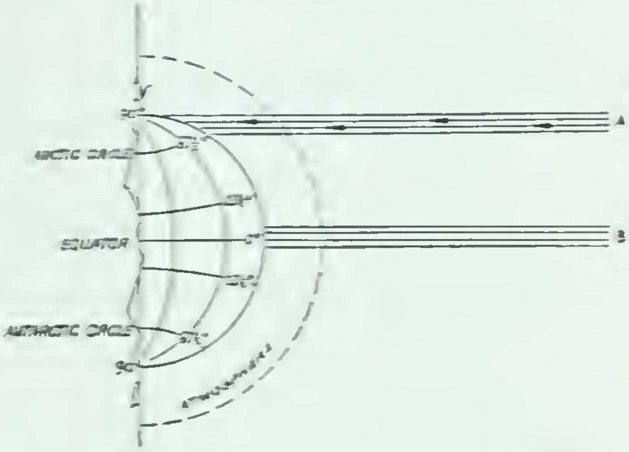


Fig. 26. Heating by radiation

Angle of radiation. The sun's rays strike the earth at different angles. The angle at which the sun's rays strike the earth's surface is a major factor in determining the amount of radiant energy that will be received per unit horizontal area, for two reasons. The accompanying diagram illustrates this. The vertical ray B delivers more energy to the earth's surface than the oblique ray A because (1) A passes through a thicker layer of reflecting and absorbing atmosphere and

Fig. 27. Diagram showing how a given unit of sun's rays has more heating effect on the earth's surface near the equator than near the poles. A and B are equal units of the sun's rays.



its energy is required to heat a larger area: and (2) it is spread over more surface.

Because the rays of the sun which strike the earth most directly have the greatest heating effect, the rate at which heat is received per unit area is less in polar than in tropical regions, less in winter than in summer, and less in the morning than in the afternoon.[1]

Absorption and reflection by the air. Oxygen and nitrogen, the major components of the air, are practically transparent to the sun's rays, although they scatter about one-third of the solar radiant energy back to space. Air which is free of foreign substances is a poor conductor of heat. The atmosphere which absorbs and reflects radiant energy contains such substances as carbon dioxide, dust, and water vapor. Water vapor absorbs a large part: and clouds reflect a great deal of the direct solar energy. The water vapor in the air, however, receives a much greater portion of its heat from the energy which is radiated from the ground than it does from the direct rays of the sun. Clouds radiate considerable heat back to the earth.

Radiation. About half of the radiant energy leaves the earth's surface. Dust and clouds, when present in the air, reflect and scatter sometimes 78 per cent of the energy waves. Clear air itself scatters and absorbs a portion. Lands covered with grass and trees reflect very little energy, while barren lands, such as deserts, reflect as much as 20 per cent, and snow reflects 70 per cent. This reflected energy is not the most important factor in the heating of the air, as will be seen later.

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[1] Maximum *daily total* amount is at South Pole in midsummer.

The remaining insolation is left to be absorbed by the land and water. Land surfaces heat very rapidly, and, in turn, cool very rapidly. Heat penetrates only the surface of the soil. Most land surfaces heat by day and cool by night. Since it takes more energy to heat water than it does most other substances, moist soil does not heat as rapidly as dry soil.

Water surfaces heat and cool more slowly than ground surfaces for several reasons:

1. Water reflects more energy than land.
2. A great deal of energy is used in evaporating the water, thereby reducing the amount available for raising the temperature of that remaining.
3. The sun's rays penetrate the water to great depths and are therefore dissipated.
4. Water is mobile and mixes quickly.
5. The specific heat of water (the amount of heat-energy required to change the temperature of unit mass through 1° C.) is several times greater than that of the soil.

Since oceans and other large bodies of water equalize their temperatures, air travel is smoother over oceans and should be very pleasant and popular. The atmosphere over oceans should offer fewer problems to the pilot than does the atmosphere over land where temperature changes and accompanying air movements are more diversified.

Conduction. The land transfers its heat to the air mainly by a process known as *conduction.* How does the land transfer its heat to the air above it? Heat is transferred from one mass to another, without transfer of the matter itself, through a process known as conduction. The air which is in constant contact with the surface of the earth increases or decreases in temperature, depending upon whether the earth is warmer or colder than the air. Conduction is always from the warmer to the colder mass. On a clear, sunny day the earth's surface absorbs a great deal of radiant energy, which is transformed into heat. If the temperature of the earth becomes greater than that of the air above it, conduction of existing heat from the earth to the air begins. If at night the ground becomes cooler than the air, heat is conducted from the air to the ground. Since air is a poor conductor of heat, only the air two or three feet above the surface of the ground is affected by conduction. Wind, however, causes the warm air near the surface to scatter and brings fresh air into contact with the earth.

In this way the air for several hundred feet above the earth's surface may be heated or cooled.

Radiation from the surface and its absorption by dust and water vapor are also of some importance.

Laboratory Exercise 24.

Equipment: A right-angle clamp, a ring stand, an 18- or 20-inch metal rod (one out of a ring stand will do), paraffin, Bunsen burner, thread, four weights.

Procedure: Tie pieces of thread about 1 inch long on each of the four tacks. Fasten the loose ends of the thread with spots of paraffin about 1½ inches apart and toward the outer end of the rod. Fasten the rod to the ring stand with the right-angle clamp as illustrated. Place burner under the end nearest the clamp.

1. Which falls first? Why?
2. What happens next? Why?
3. What are the molecules of the rod doing? Why?
4. The transfer of heat from a warm body to a cold body by molecular collision is called what?

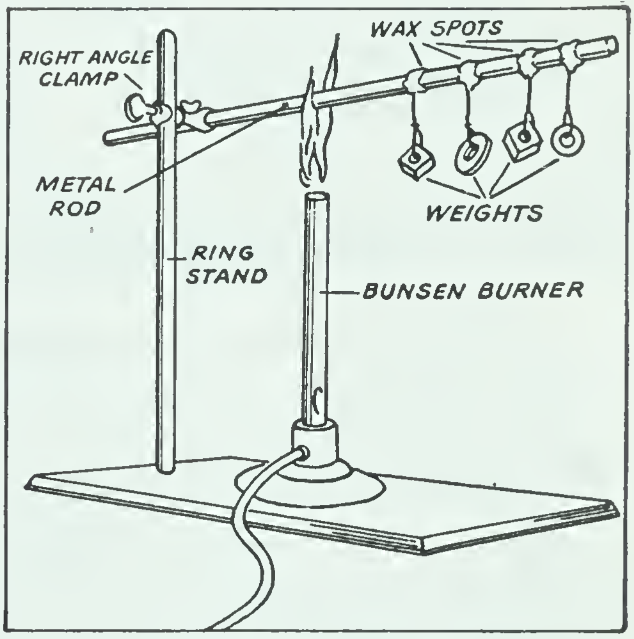


Fig. 28. Transfer of heat by conduction

Convection. It has been pointed out that the wind mixes the warm surface air with the cooler air above. There is another very important way which nature has of distributing heat from the lower air to the upper air. This process, which is known as *convection,* transfers the heat by circulating the air itself.

Laboratory Exercise 25.

Equipment: Tall lamp chimney, flat dish, metal partition, water, candle, matches.

Procedure: Fasten the candle a little off-center in the bottom of the flat dish. Put about ¼ inch of water into the dish. Light the candle. Place the lamp chimney over the lighted candle. What takes place? How do you account for the results? Remove the chimney and place the metal divider in it. Light the candle. Place the chimney over the lighted candle. What takes place? Why? Light a match; then put it out. There will be a trailer of smoke. Hold the smoking match near one side of the divider at the top of the chimney. What takes place? How do you account for what happens? Try the smoking match on the other side of the divider and explain results.

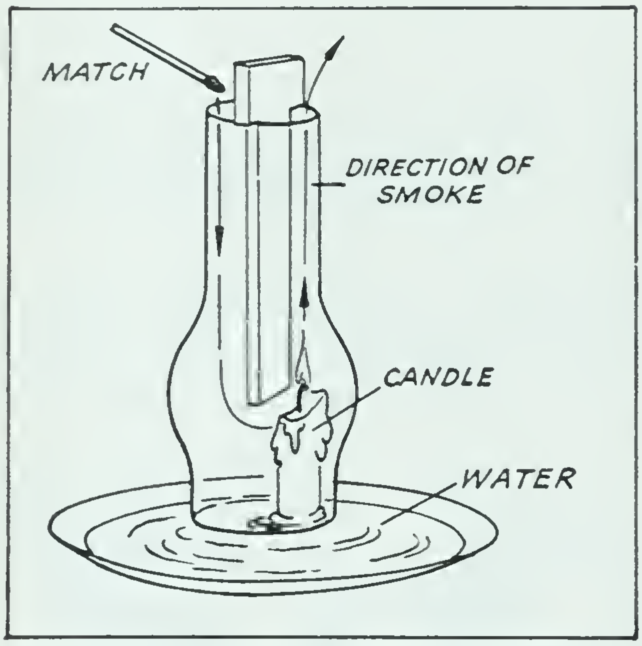


Fig. 29. Transferring heat from the lower to the upper air by convection

The surface air when heated at one point more than at another behaves much like the air in the lamp chimney. The land near the equator is constantly heated more than the land in the polar regions. This uneven heating of the earth's surface causes continual convectional circulations between the equator and the poles. This is one of the causes of the general wind systems of the globe.

Wherever there is unequal heating of any two points on the earth's surface a convectional circulation results. The oceans are warmer than the continents in winter and colder than the continents in summer. Thus convectional circulation between the air over the continents and over the near-by oceans results. The ocean is heated less than the adjacent land during the day, while at night the ocean is warmer than the adjoining land. Thus convectional circulation between the air over the land and over the ocean results. This contrasting temperature between land and water is the cause of the monsoon winds and of the land and sea breezes. Wherever irregularity in surface temperatures occurs, convectional circulation will result. Evidence of such circulation can be seen in the desert. Over the dry barren ground of the desert, dust whirlwinds are quite common. These whirlwinds are seldom seen over a vegetation-covered surface because this surface is not heated as much as is a barren surface.

Warm air. Warm air rises, expands, and cools. As air rises the weight or pressure upon it decreases; consequently it expands and grows cooler. This expansion takes place without the aid of heat by radiation or conduction. Such temperature changes are called *adiabatic* because they take place without the interchange of heat with the surroundings. The air cools approximately 1.6° F. for every rise of 300 feet. During active convection in dry air, an air traveler flying 3000 feet above the surface of the earth would find the temperature 16° F. cooler than when he left the ground.

The actual change of temperature with an increase in elevation is called the *lapse rate* of the air. The lapse rate is the rate at which the air grows colder with an increase in elevation. If the air gets warmer the rate is negative. (See Fig. 30.) The lapse rate varies widely from place to place and from time to time.

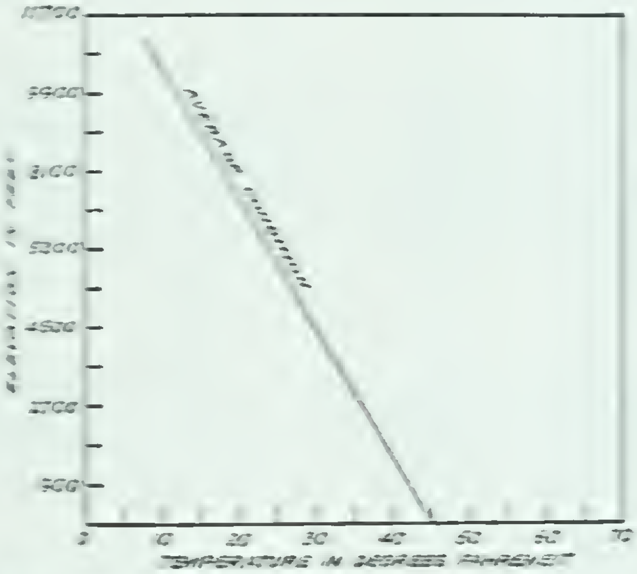


Fig. 30. Vertical distribution of temperature

Summary. The atmosphere is heated by absorption of radiant energy and by conduction of heat to it. It is cooled by emission of radiant energy and by conduction of heat from it.

When one place on the earth's surface receives more heat than another, convectional circulation results. In this way heat is transferred from one point to another by means of a circulation of the air itself.

As the air expands and cools, it may become saturated and precipitation will result. Rising air cools at a retarded adiabatic rate when condensation is taking place.

Instruments for measuring temperature. The instrument used in measuring air temperature is the *thermometer*. Galileo and Sanctorius of Padua in 1590 invented the first thermometer. More than one hundred years later, about 1714, a German physicist, Fahrenheit, developed a thermometer which bears his name. The scale he adopted for his thermometer established the freezing point of water at 32°

above zero and the boiling point for water at 212° above zero, or 180° above freezing. This thermometer is perhaps the best known, since almost every home has one. In 1742 the centigrade thermometer was invented by Celsius and Linnaeus at Upsala, Sweden. The freezing point on this thermometer was established at 0° and the boiling point at 100°. The centigrade thermometer is usually used in scientific work. The following exercises illustrate how to change a centigrade thermometer reading to a Fahrenheit thermometer reading.

Exercise 26.

Experiment: To change a Fahrenheit reading to centigrade, subtract 32° from the temperature noted; five-ninths of the remainder will equal the centigrade reading. The formula, then, will be

$$C^\circ = \tfrac{5}{9}(F^\circ - 32)$$

For example, suppose the temperature is 50° F. and you wish to know what the temperature in centigrade will be. By substituting the known temperature in the formula for F° the problem can be worked thus:

$$C^\circ = \tfrac{5}{9}(50^\circ - 32^\circ) = \tfrac{5}{9} \times 18 = 10^\circ$$

Examples: 212° F. = ?° C.; 100° F. = ?° C.; 32° F. = ?° C.; − 40° F. = ?° C.

The formula for changing a centigrade reading to Fahrenheit is:

$$F^\circ = \tfrac{9}{5}\,C.^\circ + 32^\circ$$

Suppose the temperature is 50° C., what will it be in Fahrenheit?

$$F^\circ = \tfrac{9}{5}\,C.^\circ + 32^\circ = \tfrac{9}{5} \times 50^\circ + 32^\circ = 122^\circ$$

Examples: 15° C. = ?° F.; 25° C. = ?° F.; 60° C. = ?° F.; − 40° C. = ?° F.

In addition to the conventional Fahrenheit and centigrade thermometers, the *maximum* and *minimum* thermometers and the thermograph are used to measure the temperature of the air.

The *maximum thermometer* is the same as a mercurial thermometer except for a constriction on the inside of the tube just above the mercury bulb. As the temperature increases, the mercury in the bulb expands past the constriction into the tube. When the temperature decreases, the mercury in the bulb contracts, but that in the tube remains at the highest point reached. This makes it possible for one to see what the maximum temperature during the day has been. This thermometer is usually mounted horizontally to make sure that the mercury column does not drain back into the bulb.

The *minimum thermometer* is commonly placed on the same frame with the maximum thermometer. Its liquid is alcohol instead of mercury. Inside the hollow tube is a small glass index shaped like a dumbbell. As the temperature falls, the alcohol column shortens, carrying the index toward the bulb. When the temperature rises, the alcohol expands and flows past the index, which remains at the point it reached when the temperature was at its lowest point.

The advantage of maximum and minimum thermometers over the regular thermometer is that they record automatically the highest and the lowest temperatures reached during a 24-hour period. One reading each day is all that is required.

The *thermograph* is a recording thermometer. The Weather Bureau uses it for making a continuous record of temperature variations. One device consists of a liquid sealed within a flattened, curved metal tube. One end of the tube is fastened to the supporting frame of its housing. As the temperature changes, the liquid expands or contracts, changing the curvature of the tube. A series of levers attached to the free end of the tube communicates its movements to a pen which records the

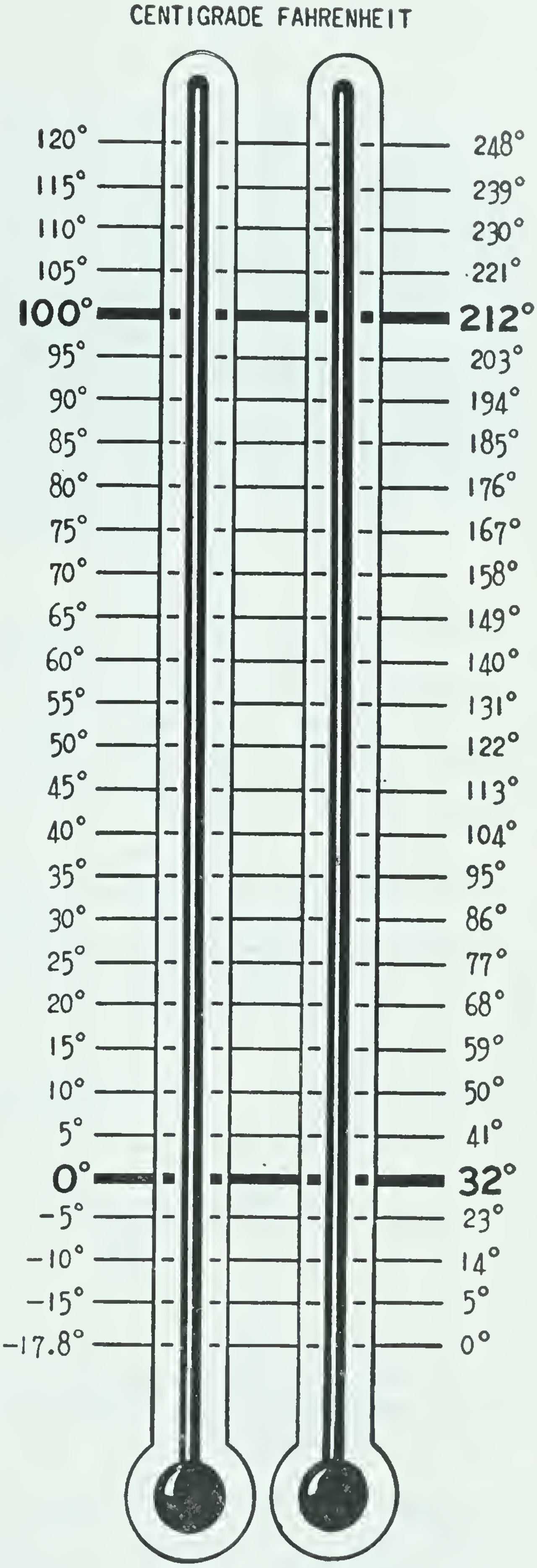
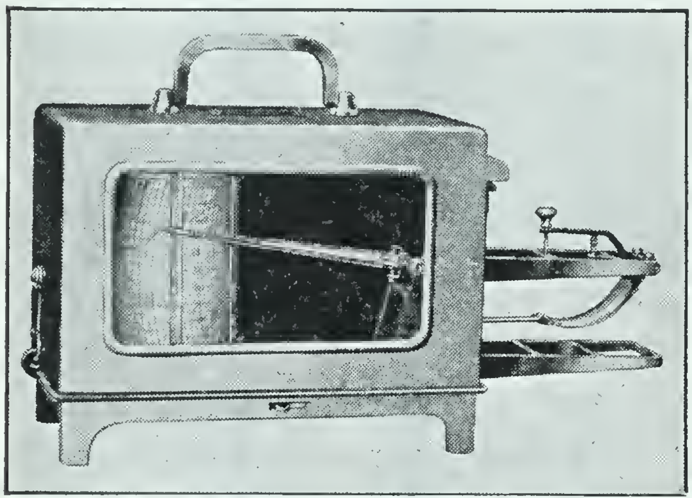


Fig. 31. A comparison of Centigrade and Fahrenheit thermometers

temperature variations on a special graph fastened to a revolving drum. It is less accurate than the mercurial type thermometer but is used extensively for general temperature observations. If from time to time corrections of its recordings are made, it becomes sufficiently accurate for more specific meteorological purposes.



Courtesy Julian P. Friez and Sons

Fig. 32. The thermograph

Temperature recording. Temperature readings are recorded on maps. Weather observations are recorded every 6 hours at over 500 different cities well distributed over the United States. These weather data are forwarded by telegraph to designated forecasting stations where a trained meteorologist places them on a map. Weather conditions reported for Kansas City, for 7:30 A.M. E.S.T., Thursday, April 18, 1940, are shown here as a sample. The temperature reading is circled with a dotted line.

On some weather maps points reporting the same temperature reading are joined together by lines. Such lines are called *isotherms.*

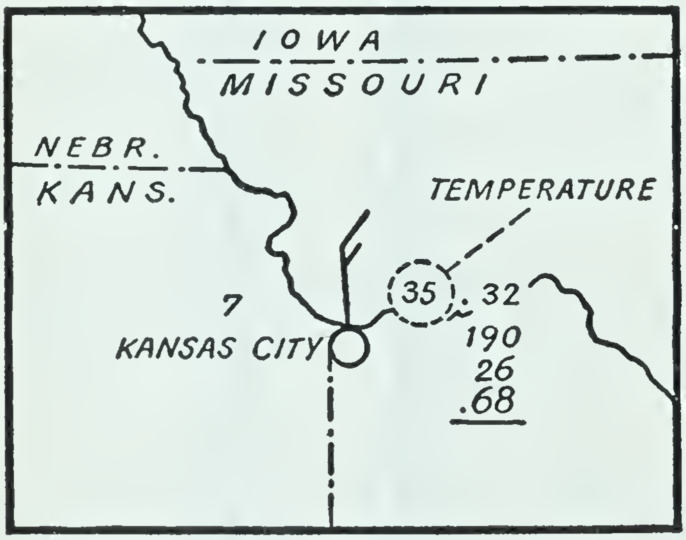


Fig. 33. The temperature reading at Kansas City

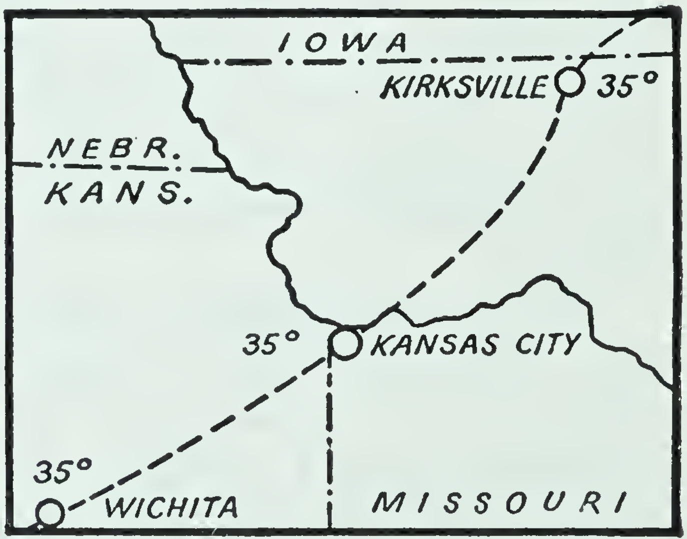


Fig. 34. The isotherm joins points of equal temperature

Isotherms may be either solid lines or dotted lines. The isotherm in Figure 34 is a dotted line. Any point on this line has a temperature of 35° Fahrenheit.

Exercise 27. What weather phenomena result from an uneven heating of the atmosphere?

Exercise 28. How is the air heated?

Exercise 29. Why do land surfaces heat and cool more rapidly than water surfaces?

Exercise 30. What use does the airman make of instruments designed for determining and recording temperature?

Air pressure and resulting wind movements. The air traveler is greatly affected by the wind. He needs to know about vertical as well as horizontal air movements. The plane usually takes off and lands against the wind. Vertical air movements may make the flight bumpy. A vertical down-draft may cause the plane to drop very rapidly. Such a rapid drop may force the plane against a hill slope or even crash it to the ground. Even the winds around the airport have to be taken into account or the plane may be upset. Wind drift is a common problem in air navigation. A tail wind or a head wind affects greatly the speed of the plane.

In the discussion of the temperature of the air the principle of convection was explained. Vertical air movements, up-drafts, down-drafts, and thermals are accounted for by this principle. At this point the two elements of weather, pressure and winds, which have much to do with horizontal or nearly horizontal air movements are presented.

Temperature and pressure. High temperature ordinarily produces low pressure and low temperatures usually result in high pressure. Air which is heated by warm land or water expands and overflows aloft to near-by regions where the temperatures are lower. The warm rising air decreases in density and hence in weight. The air which piles up in near-by cooler regions increases in density and consequently in weight. It can be said, therefore, that regions of high temperature usually have lower air pressure than do regions which have low temperatures. This difference in air pressure causes air movements, or winds.

For the first few thousand feet above sea level the rate of pressure decrease is 1 inch of pressure for each 900 to 1000 feet increase in elevation. Although the whole air mass extends to a height of more than 200 miles, more than half of the air is below 18,000 feet.

Since the human body does not adjust itself rapidly to changes in air pressure and to the oxygen content of the air, persons riding in a plane which ascends quickly are likely to experience nausea, faintness, and nosebleeds. On commercial airlines the passengers are invited to chew gum at each take-off. The chewing permits air pressure within the middle ear to adjust to that outside the body and thus

TABLE SHOWING THE DECREASE OF PRESSURE IN INCHES WITH EVERY 1,000 FEET INCREASE IN ALTITUDE

Feet	*Inches*
18,000	14.94
17,000	15.56
16,000	16.21
15,000	16.88
14,000	17.57
13,000	18.29
12,000	19.03
11,000	19.79
10,000	20.58
9,000	21.38
8,000	22.22
7,000	23.09
6,000	23.98
5,000	24.89
4,000	25.84
3,000	26.81
2,000	27.82
1,000	28.86
Sea level	29.92

prevents discomfort in the ears. Aircraft which operate at high altitudes have sealed cabins in which the air pressure is controlled.

Pressure belts and wind systems. The horizontal pattern of world pressure belts and wind systems is of interest to the air traveler. The pressure of the atmosphere varies with (1) temperature, (2) altitude, and (3) humidity. It varies from time to time at the same place and from place to place at the same altitude. It is desirable at this time to show diagrammatically the pressure belts and the resulting wind systems as they would exist on an earth composed of all land or of all water.

The diagram brings out the following points:

1. There is a belt of low pressure at the equator. It corresponds to the belt of high temperatures. This belt is known as the *equatorial low.*
2. There are two belts of high pressure at approximately 30°–40°

north and south of the equator. These belts are known as the *subtropical highs.*

3. There are two low-pressure areas in the vicinity of the arctic and antarctic circles. These are the *subpolar lows.*

4. There are two high-pressure areas associated with the poles. These are called *polar highs.*

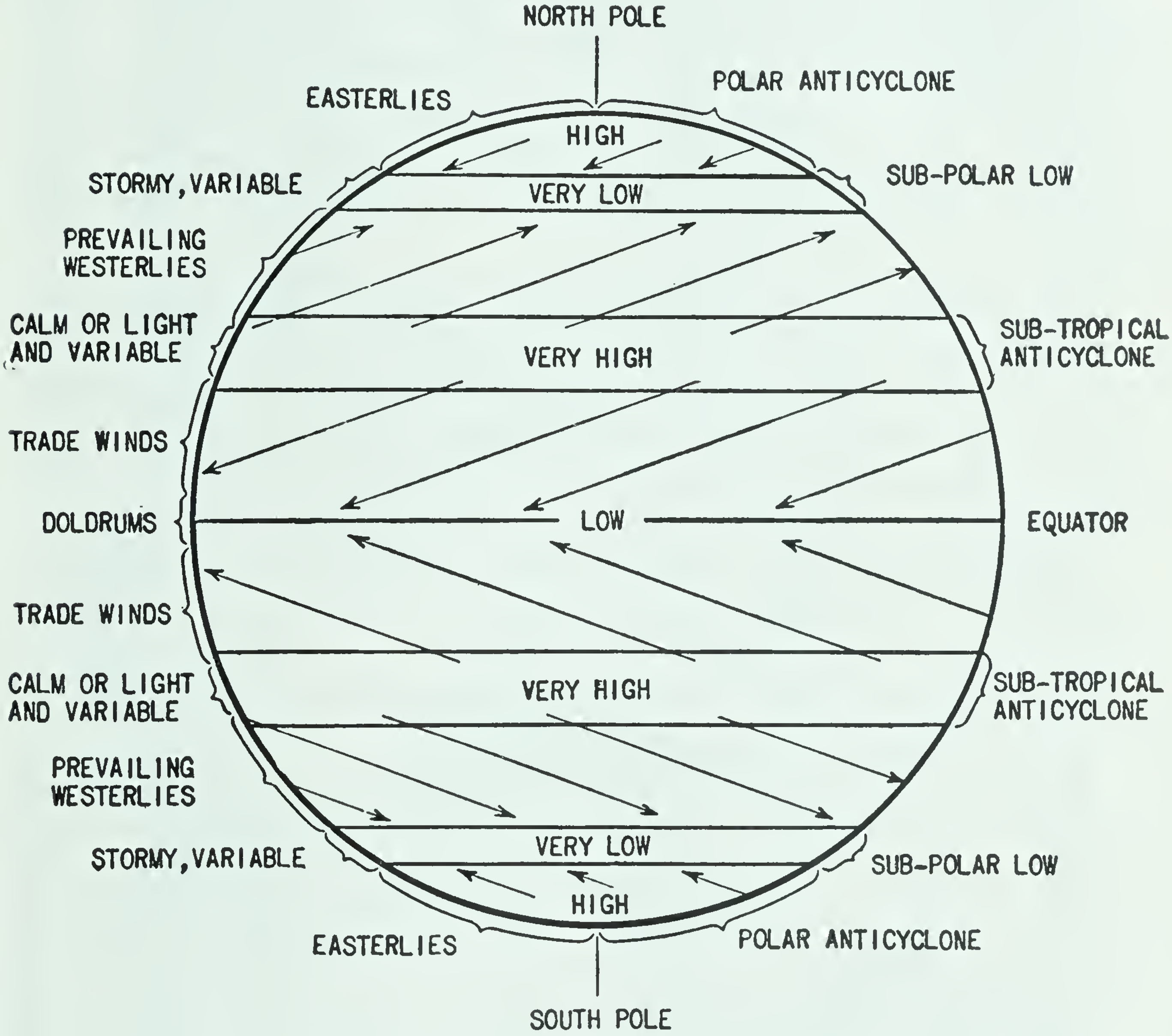


Fig. 35. Generalized diagram of pressure belts and associated wind systems on the earth's surface

The principle which we have learned about the relationship which exists between temperature and pressure (cold temperatures cause high pressure, and warm temperatures give low pressures) does not seem to apply to the subtropical highs and the subpolar lows. The subtropical highs are not in regions of excessive cold; nor are the subpolar lows in regions of excessive heat. These two pressure features are associated with rotation.

The warm air overflow aloft at the equator moves forward into higher latitudes. These north and south winds are deflected more and more because of the rotation of the earth, until by the time they reach latitude 30°–40°, almost 90° deflection has been reached. (See Fig. 35.) At this latitude the poleward-moving air piles up and thus establishes the two subtropical high-pressure belts.

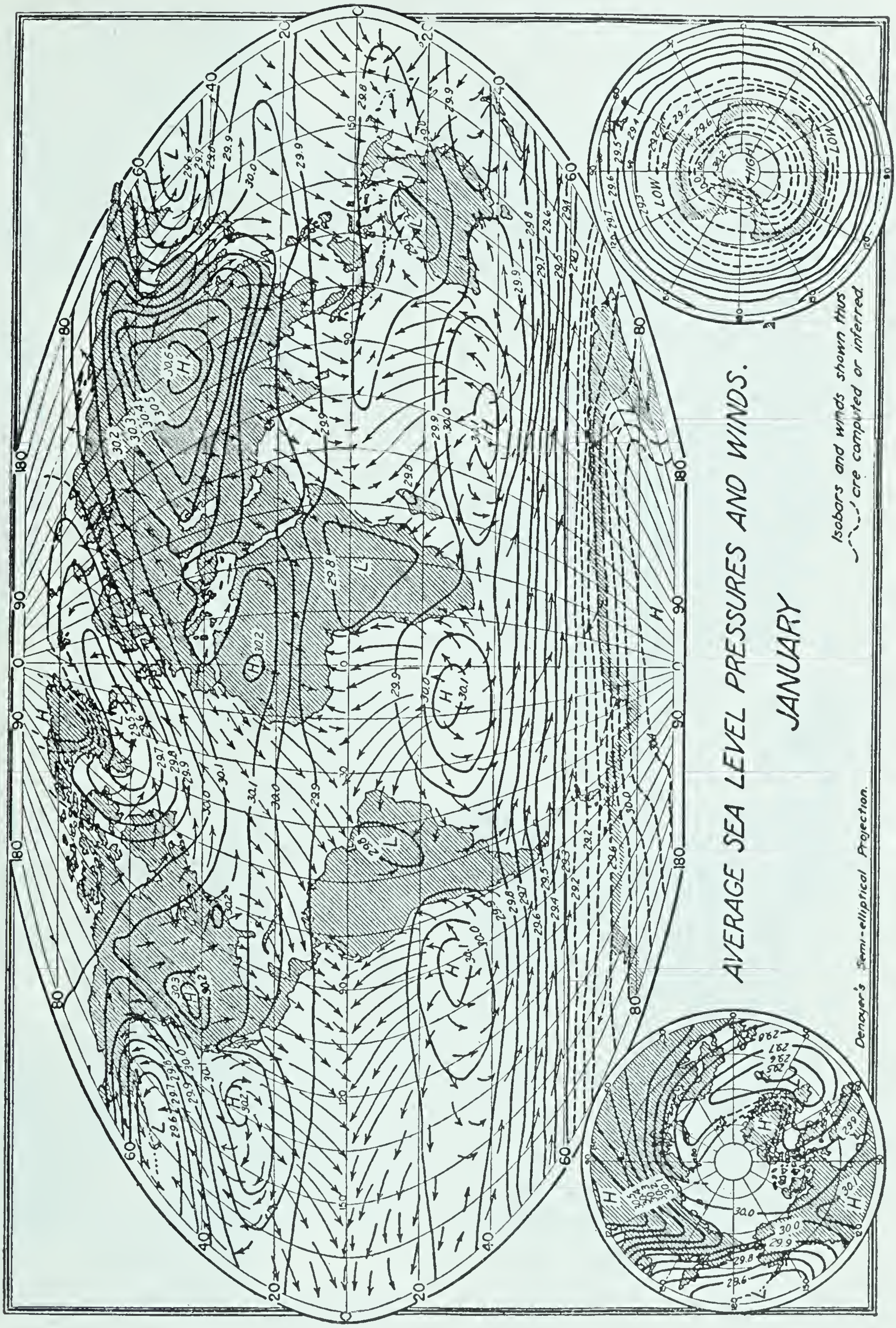
Some of the air from the equator moving at very high altitudes spirals in toward the poles. Its radius of rotation has decreased, and its velocity of rotation has increased. The resulting centrifugal force developed acts to urge it away from the polar areas much as water escaping from a circular basin is held away from its center. Thus polar lows develop not at the poles but at the antarctic and arctic circles.

It is possible to show these belts of high and low pressure and accompanying winds on a map. Since the pressure belts shift to the north and the south, following the sun, the maps for both January and July are included. The lines on the map which show pressure are called *isobars.* Isobars are lines connecting places having the same average pressure. Pressure readings are always reduced to sea level.

Wind and pressure. Wind is nature's way of correcting pressure inequalities. Air moving essentially parallel to the earth's surface is known as *wind.* Air moving vertically from the earth's surface is properly called a *current.* Most people, however, use the term *wind* for both horizontal and vertical air movements.

Wind is caused by differences in air pressure. In the northern hemisphere the direction of the wind is clockwise around an area of high pressure and counterclockwise around an area of low pressure; in the southern hemisphere the directions are the opposite. The velocity, or speed, of the wind depends upon the rate of change of air pressure. If the change in pressure is rapid, the wind will be strong. If, on the other hand, the change in pressure is gradual, the wind will be weak.

The rate and the direction of the change of air pressure are shown on a map by the use of isobaric lines. If the isobaric lines are far apart, the wind and pressure change is not marked. Consequently winds from this source would be weak. Under such conditions the *pressure gradient* or *barometric slope* is said to be weak. If the isobaric lines, however, are close together, the rate of pressure change is marked and barometric slope is steep and strong. Line *A* drawn at right angles to the isobar shows pressure gradient; the direction of


AVERAGE SEA LEVEL PRESSURES AND WINDS.
JANUARY
Isobars and winds shown thus are computed or inferred
Denoyer's Semi-elliptical Projection.
HIGH
LOW
H
L

From Finch and Trewartha's ELEMENTS OF GEOGRAPHY
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Fig. 36. Average sea-level pressures and winds: January

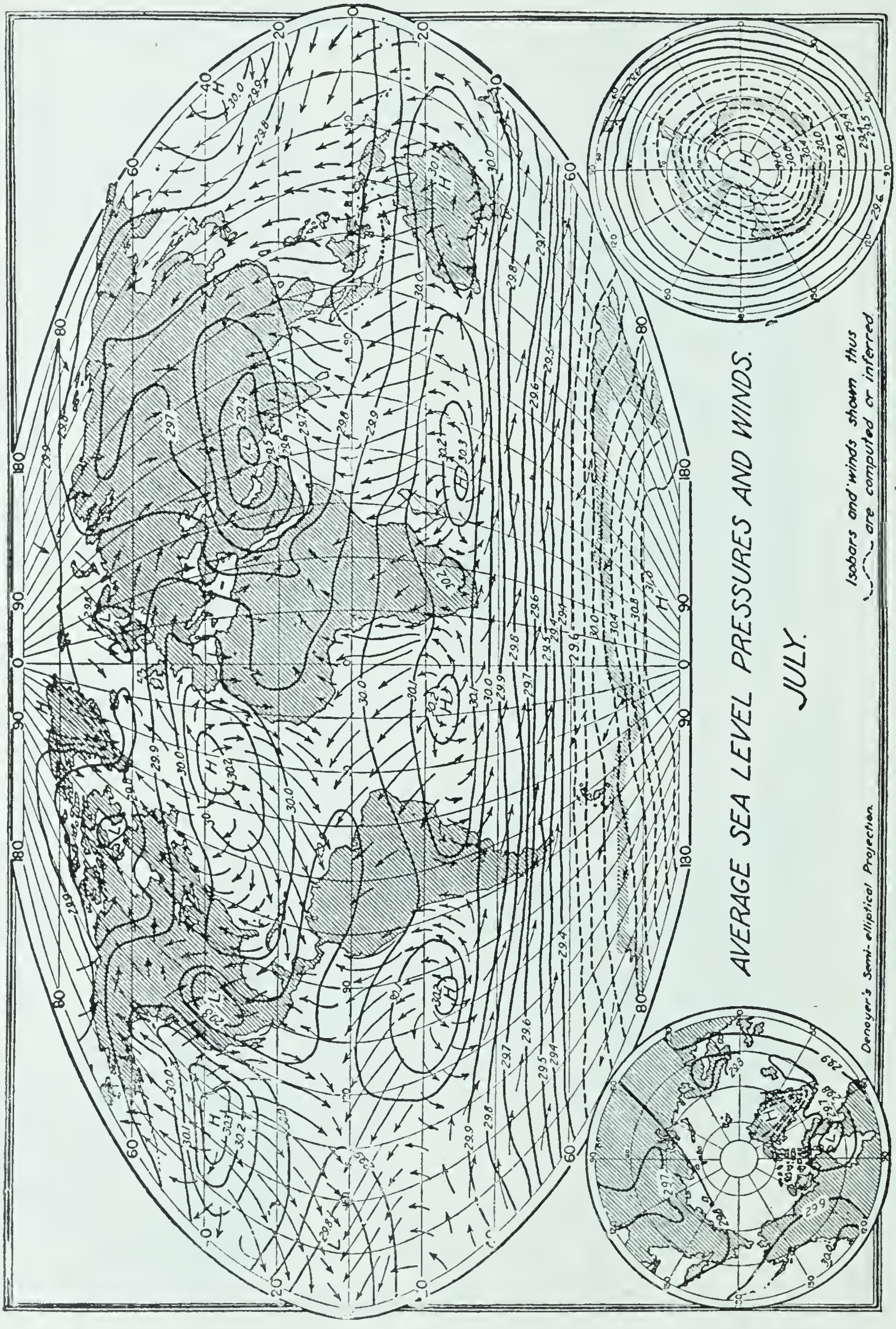
AVERAGE SEA LEVEL PRESSURES AND WINDS.
JULY.
Isobars and winds shown thus are computed or inferred
Denoyer's Semi-elliptical Projection.

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Fig. 37. Average sea-level pressures and winds: July

the wind is usually approximately along the isobars, that is, perpendicular to the gradient.

INSTRUMENTS FOR MEASURING AIR PRESSURE

The mercurial barometer. Because of the constant changing of the temperature and moisture content of the air there is a continual changing of air pressure above the earth's surface. Since human beings cannot readily detect these pressure changes, Torricelli's invention (see Fig. 39) has been one of man's most important aids. With this device Torricelli discovered that the height of a column of mercury would vary from day to day and he concluded that pressure changes could be measured by placing a scale behind the tube of mercury. This instrument is known as a Torricelli Mercurial Barometer.

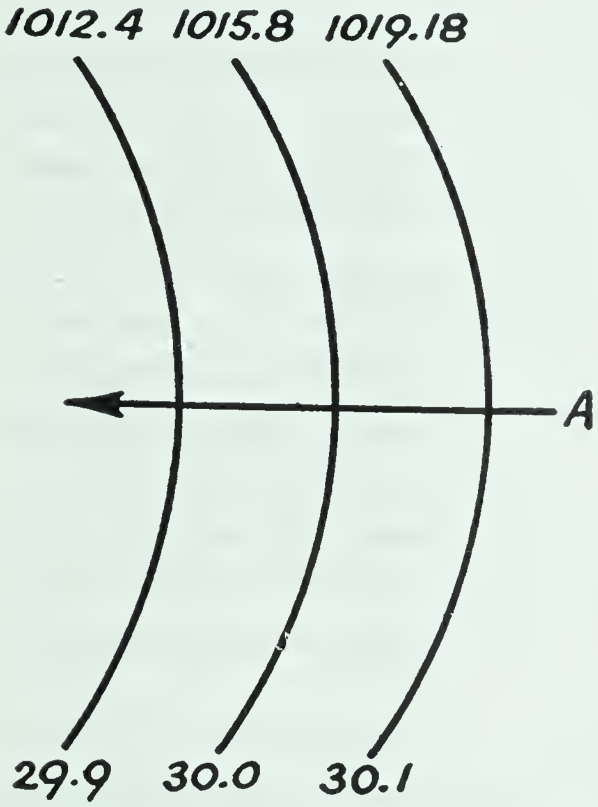


Fig. 38. The pressure gradient is represented by the line drawn at right angle to the isobar

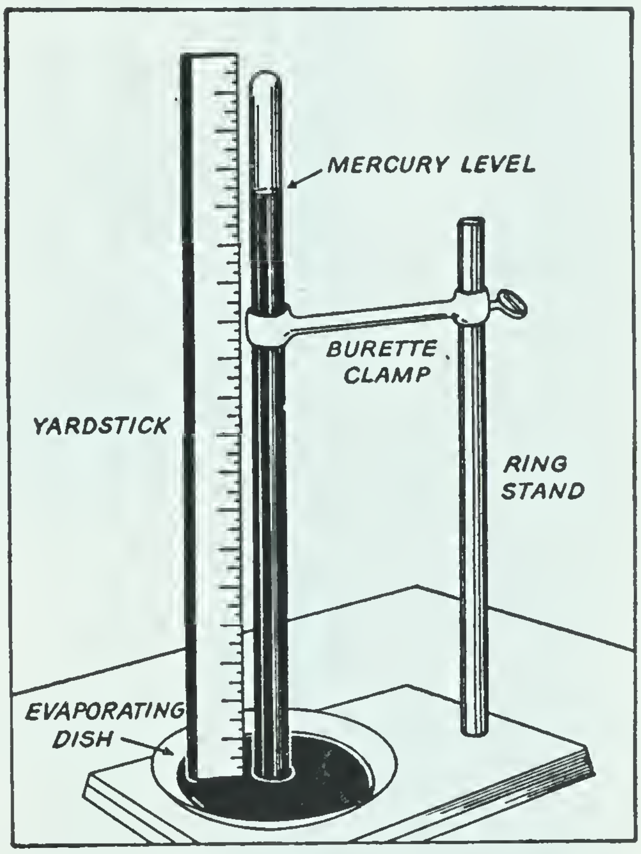


Fig. 39. A homemade mercurial barometer

Laboratory Exercise 31.

Equipment: Evaporating dish or cup, yard rule, 34-inch length of 7 mm. glass tube (this tube should have thicker walls than the ordinary tube), ring stand, burette clamp.

Procedure: Seal one end of the tube. Fill the tube with mercury.

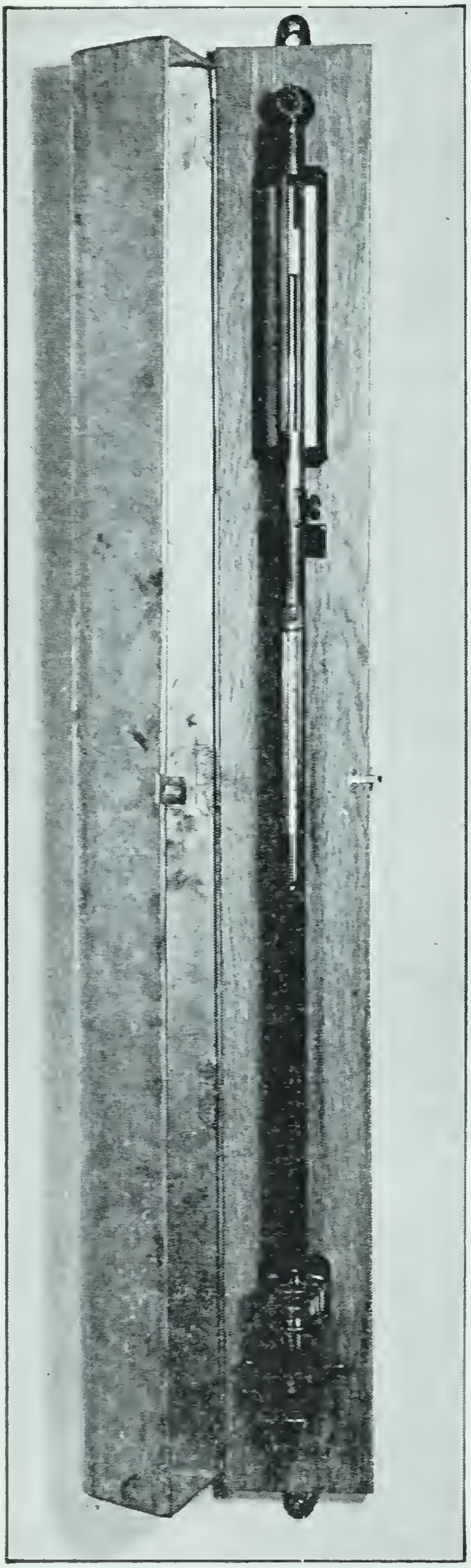


Fig. 40. The mercurial barometer is attached to the wall in a horizontal position.

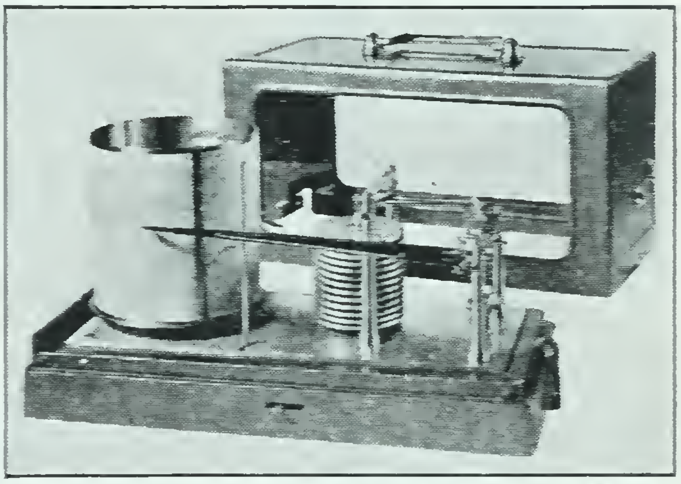
Place the index finger over the open end and slowly invert the tube into a cup of mercury. When the open end of the tube is submerged sufficiently into the dish of mercury, withdraw the finger. A small amount of mercury will run out of the tube into the dish, leaving a vacuum above the column of mercury. Fasten the yard rule parallel to the tube with its lower end at the surface of the mercury in the dish. The top of the column of mercury will coincide with a certain figure on the yard rule. This figure is proportional to the pressure of the atmosphere at that particular time and place. Observations of the variable pressure of the air can be made by watching the column of mercury rise and fall from day to day or from hour to hour.

From the principle of Torricelli's barometer the Fortincistern barometer was developed. Because of the precision of its design and the accuracy with which it can be read the Weather Bureau has adopted it as a standard measure.

The aneroid barometer. A more universally used instrument for measuring atmospheric pressure is the aneroid barometer. It consists of a hollow corrugated metal wafer from which some of the air has been exhausted. A spring is inserted within the wafer to keep the sides apart. As the air pressure increases, the metal walls of the wafer are compressed, actuating a series of levers which move a pointer around the face of a dial that has been calibrated to correspond to the reading of a mercurial barometer. Therefore, if a column of mercury stands at 30 inches, the hand on an aneroid barometer will also point to 30 inches. On weather maps it is becoming customary to use the metric system and to express atmospheric pressure in terms of millibars. The pressure exerted by a column of mercury 30 inches in height is equivalent to a pressure of 1015.8 millibars.

The aneroid barometer is rather rugged in construction and can be moved about with considerable ease. Since the atmospheric pressure becomes less with an increase in altitude, the aneroid barometer, when calibrated to read in thousands of feet instead of in inches, becomes an altimeter—one of the most important instruments in an airplane, particularly when flying in weather which obstructs vision.

The barograph, Figure 41, is an instrument which records the variations in air pressure on a special graph fastened to a revolving drum. It is used for keeping a continuous account of the variations in air pressure during the day.



Courtesy Julien P. Friez and Sons

Fig. 41. The barograph

Winds are always named after the direction from which they blow. A wind from the west blowing to the east is a *west wind,* a wind from the southeast blowing to the northwest is a *southeast wind.* The wind vane points toward the source of the wind, or toward the barometric slope down which the air is moving. The velocity of the wind is recorded by an instrument known as the *anemometer. Windward* refers to the direction from which the wind comes. *Leeward* refers to the direction toward which the air blows. In the state of Washington, where the winds blow from the west, the west slopes of the mountains are the windward slopes; the east slopes are the leeward slopes. When a wind blows generally from one direction, it is called the *prevailing wind.*

Exercise 32. What is the relation between air pressure and winds?

Exercise 33. How do the horizontal and vertical wind movements affect flying?

Exercise 34. Compare the January and the July pressure maps (Figs. 36 and 37). Why is it that isobars over the continents tend to bend poleward in January and equatorward in July?

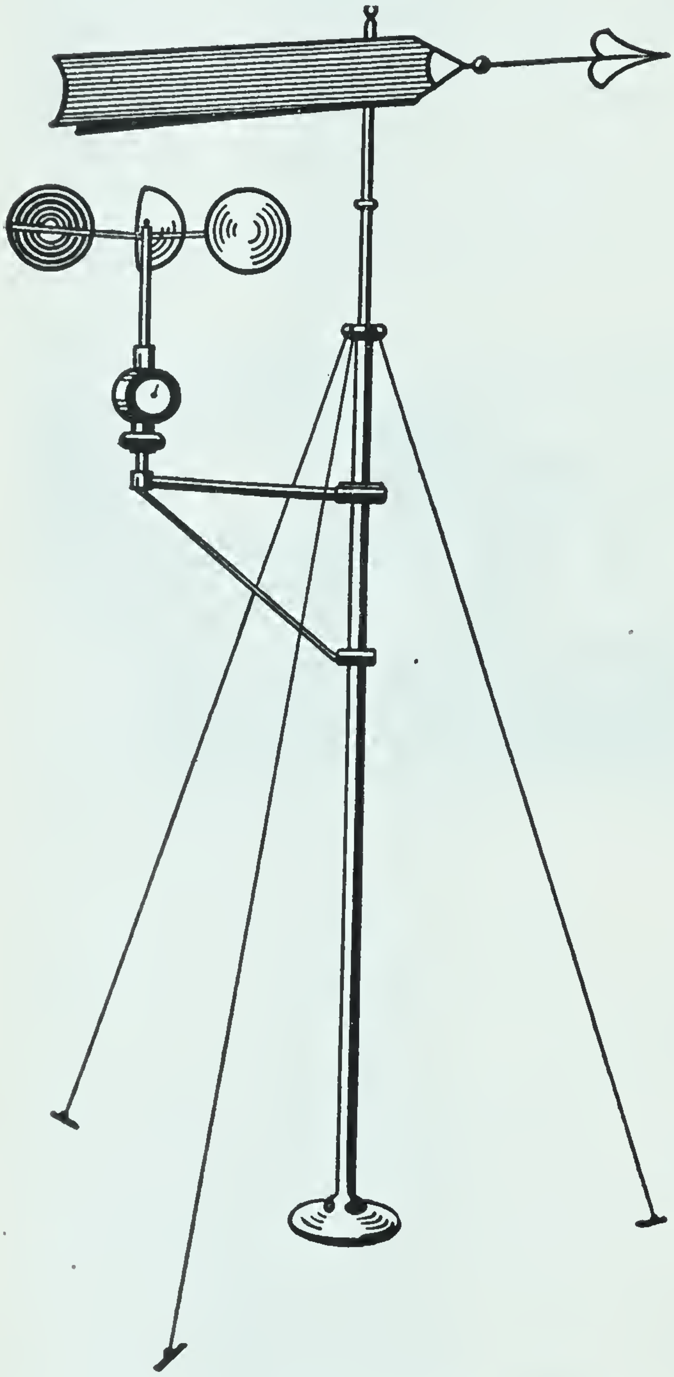


Fig. 42. The weather vane and anemometer

Exercise 35. Why do areas of high pressure develop over the continents in January and over the oceans in July?

Exercise 36. Why do winds blow out from the interior of Asia in January and toward the interior in July?

Exercise 37. Why do the major pressure belts move poleward in the summer and equatorward in the winter?

Exercise 38. Following the arrows on the maps, locate the trade winds and westerly winds.

Exercise 39. Name and discuss the elements of the weather.

Exercise 40. Indicate how each element listed in the previous exercise affects directly the air traveler.

Problem 3. How does the pilot determine wind direction while in flight?

Because the wind is constantly shifting and it is not always possible for a pilot to identify its direction, all airports are equipped with a *wind sock* (see Fig. 43). It consists of a white cloth approximately 10 feet in length, shaped like an open cone, and tapers from 2 feet in diameter at the mast end to about 1 foot in diameter at the trailing end. Wind blowing in at the larger end fills the hollow cone, which trails out in the direction of the airflow. Being relatively large, it is easily visible from the air.

Some airports employ another type of wind vane called a "T."

It is a block model of a plane designed to swing freely about its vertical axis. When the wind blows, the "T" plane (see Fig. 44) heads its nose in the direction from which the wind is blowing. Because of its size it can be seen from a considerable altitude. Some of these devices are also equipped with electric lights which make them visible from a plane at night.

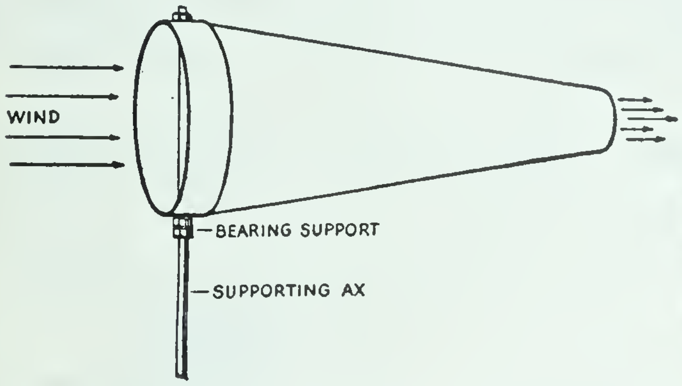


Fig. 43. A wind sock

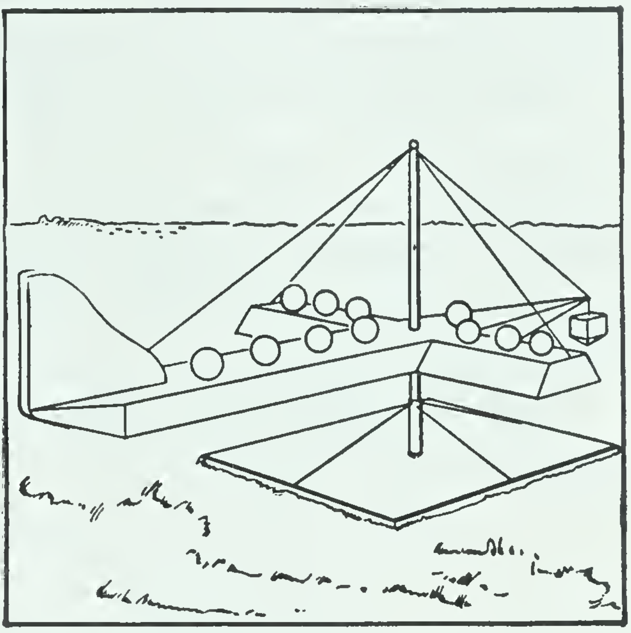


Fig. 44. The wind "T"

Most of the larger, terminal airports are equipped with radio and are able to inform pilots of planes so equipped about the wind direction and velocity as well as about other details concerning the weather. However, a more complete explanation of the uses of the radio in aviation is given in Unit V, entitled "Aircraft Communications."

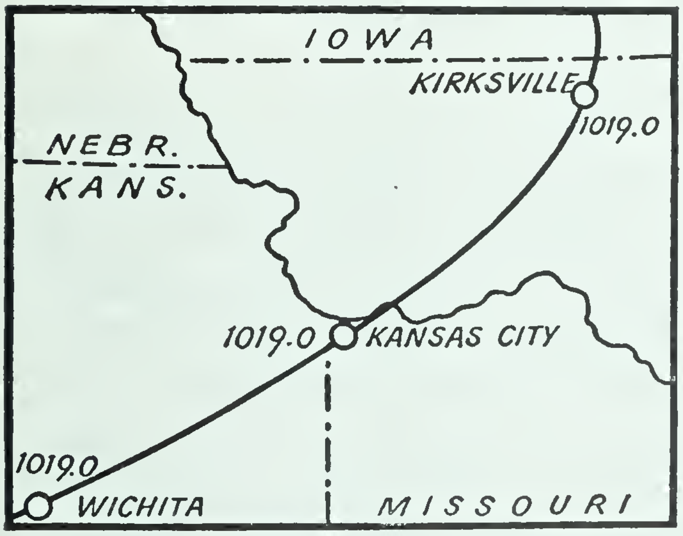


Fig. 45. An isobar which joins points of equal air pressure

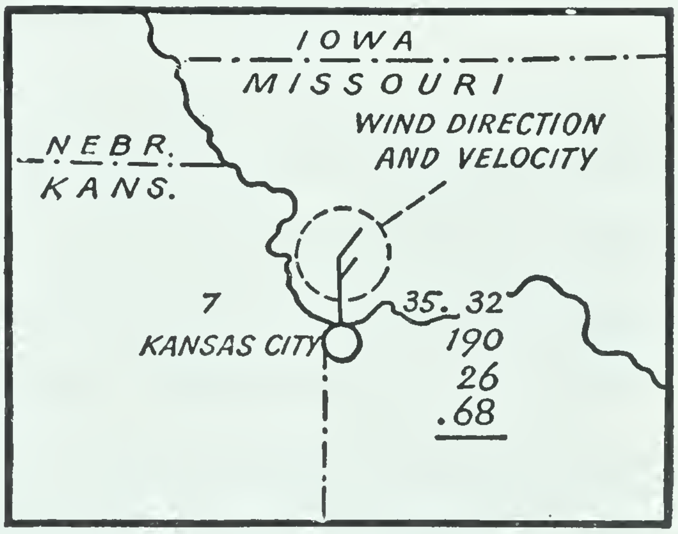


Fig. 46. A symbol which shows the direction and velocity of the wind

Pressure recordings. Pressure readings are recorded on maps. One of the most important observations of weather is that of pressure. Among the weather conditions reported for Kansas City for 7:30 A.M.

E.S.T., Thursday, April 18, 1940, was the sea-level air pressure 1019.0 millibars. At Wichita, Kansas, and Kirksville, Missouri, the sea-level air pressure was also 1019.0 millibars. The continuous line drawn through these points is called an *isobar*. All other points along this isobar will have the same pressure reading.

The direction and the velocity of the wind are recorded on all airway weather maps. In Figure 46 the wind is moving in from the north as shown by the arrow connecting Kansas City. The feathered end of the arrow represents the wind velocity at that point, which is from 8 to 12 miles per hour. More feathers on the arrow would indicate a greater velocity.

Air movements and the pilot. The direction, character, and velocity of the wind are of constant concern to the pilot. At the take-off he heads his plane into the wind. As he lands he likewise heads his plane into the wind. If the wind is strong, the plane will leave the ground with a short run; if the air is still, however, the plane must have a much longer run in order to develop sufficient speed to lift it from the ground. On a very windy day the amateur should not attempt a flight because of the danger involved.

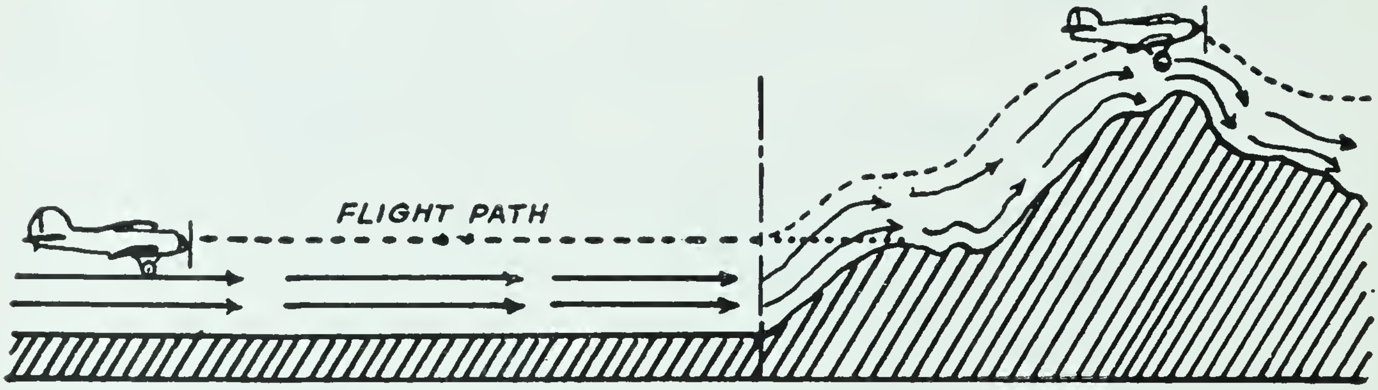


Fig. 47. Air movements vary with topography

It is possible, and in an emergency it may be necessary, to take the plane off or land it sidewise or with the wind. This is a dangerous practice, however, and should not be followed except when necessary, because sudden gusts or currents of air may upset the plane.

Wind turbulence and eddies. Wind turbulence and eddies affect flight. Often the pilot encounters sudden or unnatural disturbances of the air. The air moving horizontally to the earth's surface comes in contact with many objects, thus developing friction at contact points. Friction causes the atmosphere to pile or roll up at points of contact. The situation is similar to that of a hay rake which rolls up the hay and deposits it in windrows. This piling, or rolling up, of the air is known as *turbulence*. Under ordinary circumstances it does not affect take-offs and landings.

Turbulence may also be caused by convectional currents which run head-on into horizontally moving winds. *Eddies,* which are smaller disturbances and are nearer the ground, likewise develop under similar situations.

Topography and wind. Topography influences the wind. A horizontal wind blowing over a flat land surface is likely to be quite regular. In contrast, however, wind blowing over irregular land surfaces is usually characterized by up-drafts and down-drafts. The effect of topography on wind movements is shown diagrammatically in Figure 47. A plane flying over a flat landscape usually has a smooth flight. When a plane traveling in the same direction with the wind approaches a mountain, the up-drafts may cause the plane to rise very rapidly. A plane can escape wind disturbances caused by irregular land surfaces by flying sufficiently high to avoid the turbulent surface winds.

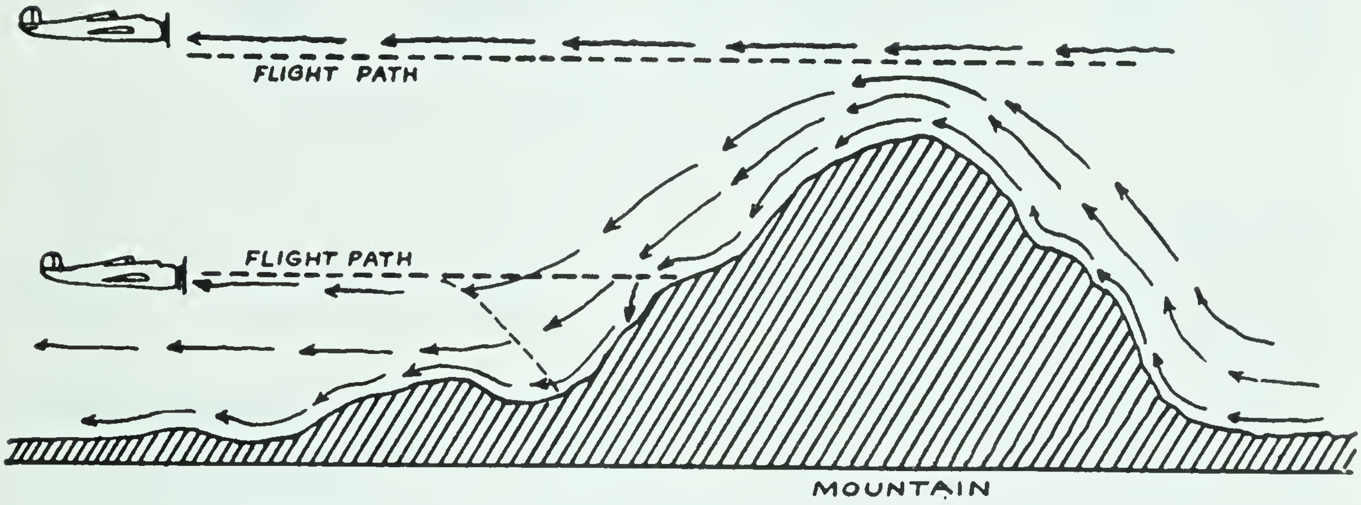


Fig. 48. Headwind flight over a mountain

A plane heading into the wind would usually have a smooth ride over flat surfaces. If it were to approach the leeward side of a mountain, it might be caught in a down-draft and be unable to gain sufficient altitude to fly over the mountain. A crash might result. In order to avoid down-drafts the pilot must fly across irregular terrain at much higher altitudes than those that are safe over flat country. (See Fig. 48.)

A plane flying over both land and water surfaces during the day can more commonly expect to experience up-drafts over the land and down-drafts over the water. During the night the reverse would be true. This is due to the fact that land heats more rapidly than water. Other causes of up-drafts and down-drafts are clouds, woods, cities, canyons, and other irregular land surfaces. (See Fig. 49.)

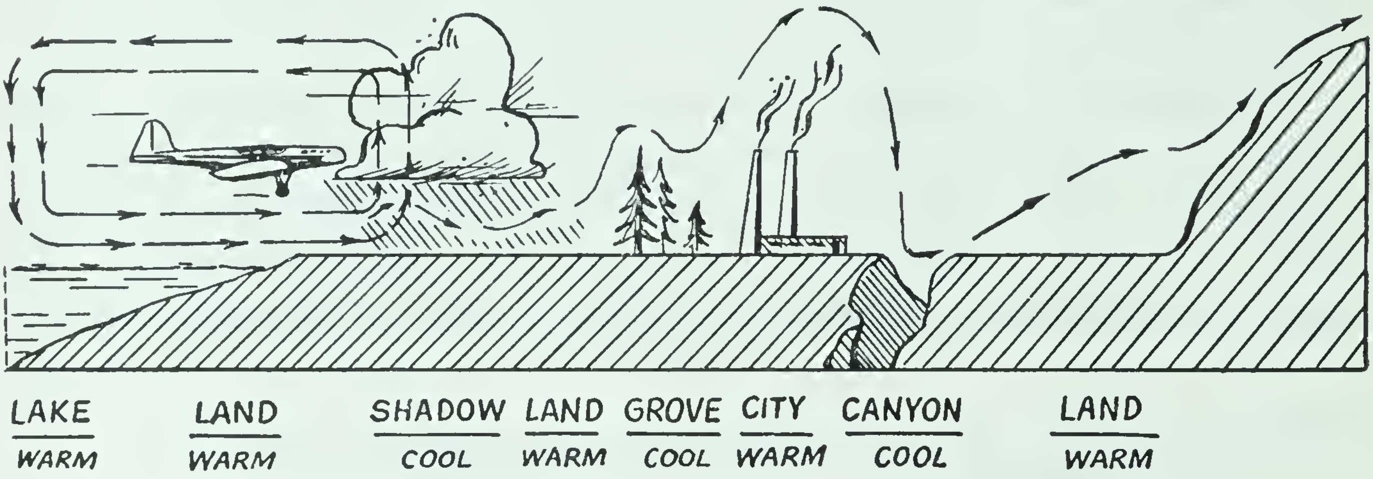


Fig. 49. Updrafts and downdrafts during the day

Laboratory Exercise 41.

Equipment: 1 gallon of water, 1 gallon of earth, 2 Bunsen burners.

Procedure: Place the water and earth over the Bunsen burners. Allow them to heat for about 3 or 4 minutes. Now pour the water into a basin and tip the earth upside down on a board. Put one hand in the water and test the earth with the other hand. Is there any difference in the temperatures? Which is the hotter? Why?

Laboratory Exercise 42.

Equipment: Large pan of water.

Procedure: On a warm day place a large pan of water out of doors near a sidewalk. About an hour later test both the water and the sidewalk. Which is warmer? Why?

The up-drafts and down-drafts that a plane encounters while in flight are called *bumps.* Bumps are more frequent during the day than during the night. They may be encountered as low as 50 feet and as high as 2800 to 3000 feet. The layman has erroneously called down-drafts "air pockets."

A plane on a long-distance flight is very likely to encounter a shift in wind direction. This shift will occur when the plane passes from an area of cold air to an area of warm air. The reverse is also true. The pilot needs to be aware of conditions prevailing along such wind-shift lines.

Moisture in the air. Clouds cast long shadows over the land and thus shelter crops from the scorching sun. They control the mid-summer's heat. Flowers lift their heads to drink in the precious showers which they bring. If it were not for the clouds, life would not be possible on this earth.

Sometimes clouds are very unfriendly to man. There are times when they bombard the earth with hail. Streams overflow their banks and destroy crops and homes in the valleys. Tornadoes on land and typhoons on the sea may destroy fields, homes, and human life.

To the air traveler clouds mean all of these things and many more. Clouds help him predict the weather so that he knows when to fly and when not to fly.

The pilot has a box seat in the sky from which he views the parade of the clouds. Some are friendly little fleecy white bundles, others are towering giants of destruction. The pilot is continually aware of their mock plains, valleys, mountains, and canyons. Oftentimes he travels above the clouds. It is true that aviators may cross the ocean and never see the water because clouds have formed a canopy over the ocean.

Water vapor. Water vapor is one of the most essential components of the air. But for water vapor temperatures during the day would rise to extreme heights and would drop many degrees below zero at night. Without water vapor there would be no clouds in the sky to protect us from the heat, to keep the sun from burning crops and destroying vegetation.

CONSTITUENTS OF THE ATMOSPHERE
(Percentage by Volume)

WATER VAPOR	NITROGEN	OXYGEN	ARGON	CARBON DIOXIDE AND OTHER GASES
0.2	77.34	21.46	0.95	0.07
0.8	77.47	20.73	0.94	0.06
2.6	75.97	20.46	0.93	0.04
4.0	74.88	20.16	0.94	0.02

Water vapor constitutes only 4 per cent of the volume of the air under even extreme conditions. Nearly all of the water vapor in the air is found below an altitude of 25,000 feet. The accompanying table illustrates the percentage relation of all atmospheric gases to water-vapor content.

Evaporation and condensation. The air is constantly gaining and losing water vapor. The principal source of water vapor is the oceans, although some water vapor comes from smaller bodies of water, from wet land surface, and from vegetation. The sun uses up a great deal of its energy changing water, which is a liquid, into water vapor, which is an invisible gas. The change is brought about by a process known as *evaporation*. The rate of evaporation depends upon the amount of solar energy which the sun is giving off at any particular time. During the summer when the temperatures are very high, if the moisture content of the air is also high, the weather is disagreeable. As soon as rain falls, some of the vapor is released.

The maximum amount of vapor that can exist in the air increases with rising temperatures. The total amount of water vapor that a unit of air contains at any one time is called the *absolute humidity* of the air. The amount of water vapor in a given unit of air at any given time, as compared with the amount that could be in it and not precipitate, is called the *relative humidity* of the air. When air is cooled the maximum possible amount of moisture decreases. If the air continues to cool, the saturation point will be reached. This is known as *dew point*. If the temperature continues to fall below dew point, there will be more water vapor than can continue to exist. *Condensation* will then take place and some of the water vapor will be changed into raindrops or particles of ice and snow. Cooling the

TEMPERATURE IN FAHRENHEIT	ABSOLUTE HUMIDITY Grains	RELATIVE HUMIDITY Per Cent Saturated
50	4.1	100
60	4.1	71
70	4.1	51
80	4.1	36
90	4.1	27
100	4.1	19

air below dew point is, then, the one way to cause precipitation. If the relative humidity is high, and the air is close to saturation point, only a small amount of cooling will bring about rain or snow. On the other hand, if the relative humidity is low, much cooling of the air is necessary if precipitation is to result. Such conditions usually exist over desert regions. The table on page 96 shows how air which was saturated at 50° decreases in relative humidity by increasing its temperature, the water-vapor content remaining unchanged.

Laboratory Exercise 43.

Equipment: A sponge and a basin of water.

Procedure: Before immersing the sponge in the basin of water, note how porous it is. Imagine, if you can, that the sponge represents a parcel of the atmosphere, and that its open spaces represent the distances between the molecules. Now press the sponge tightly and immerse it in the basin of water. While it is still submerged release it and lift it from the water. Holding it on the palm of your dry hand (over the basin) you will note that the sponge is so completely filled that some of its water (water vapor) will drain out of the sponge. Dry your hand. Now squeeze the sponge until it is about half full and place again on your dry hand. Does the water continue to run out of the sponge? Did your hand become as wet this time? Why? With increased pressure (density) can the sponge hold as much moisture as in decreased pressure (density)? Why?

Laboratory Exercise 44.

Equipment: A glass pitcher, drinking glass, or metal container, ice, and water.

Procedure: In a warm room fill the pitcher with cold water and add ice to lower its temperature. Set the container on the table. Notice the moisture gathering on the side of the cold container. How does it happen that moisture collected on the container? What does the moisture look like?

Laboratory Exercise 45.

Equipment: A flask, one-hole rubber stopper, glass tube, water, and air pump.

Procedure: Cover the bottom of the flask with water. Insert rubber stopper and tube in flask. Blow air into the flask until there is enough pressure to blow out the cork. What happened in the flask? Explain.

The wind carries moisture-laden air from place to place. Cooling processes condense some of the moisture, which then falls as rain or snow.

Precipitation. Cooling the atmosphere causes precipitation. There are several ways of cooling the atmosphere. Air which comes in contact with cold land surfaces is cooled. This condition exists when the air is still. If the wind is blowing, the surface air does not remain in contact with the cold earth long enough to be chilled. Dew, frost, and hard freezes may occur on cold still nights. In such in-

TYPES OF CLOUDS *

FAMILY	TYPE	AVERAGE BASE LEVEL *Feet*	DESCRIPTION	ABBREVIATION
A	1. Cirrus	32,000	Thin, wispy, featherlike	Ci
High	2. Cirro-stratus	28,000	Very thin, sheetlike	Cs
Clouds	3. Cirro-cumulus	22,000	Thin, flakelike	Cc
B	4. Alto-stratus	17,000	Medium, high, sheetlike	As
Middle Clouds	5. Alto-cumulus	15,000	Woolly, sheepbacklike	Ac
C	6. Strato-cumulus	5,000	Rolls, globular masses	Sc
Low	7. Nimbo-stratus	3,000 2,000	Low, amorphous, rainy	Ns
Clouds	8. Stratus		Low, sheetlike	St
D	9. Cumulus	1,500	Dome-shaped, dense	Cu
Vertical Clouds	10. Cumulo-nimbus	1,500	Towerlike, cauliflowerlike, cirrus top	Cb

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* In the following pages, one member only of each family will be described.

stances the surface air temperature is reduced below the original dew-point temperature.

Whenever a mass of moisture-laden warm air from the warm latitudes comes into contact with a cold-water surface or land surface, the cold surface cools the warm air and *advection fogs* result.

It has been pointed out that when air rises it expands and cools. This is true because there is less weight upon it at the higher altitudes. The rate of cooling or heating of non-saturated moving air is about 5½ degrees per 1000 feet. Cooling which results from the expansion of rising air currents is the one process capable of causing large masses of air to give up their moisture. The direct result of cooling due to rising air currents is *clouds.* Clouds are forms of condensation found in the upper air much as dew, fogs, and frost are common to the surface air. Fog and clouds are identical except that they occur at different distances from the ground. Not every cloud gives off precipitation.

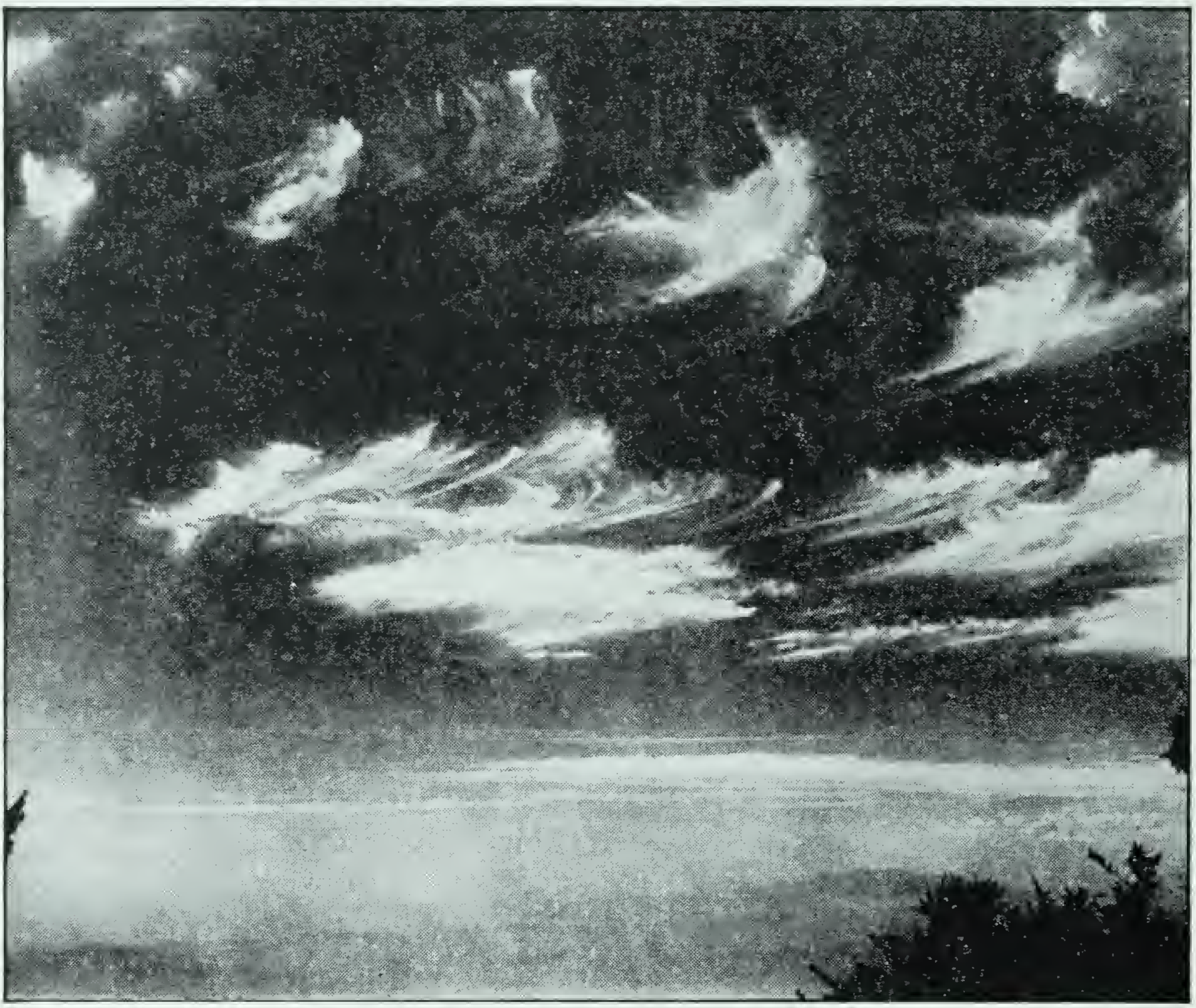
If ascending cooling air reaches a temperature of 32°, the condensed liquid particles may be in the form of snow or hail.

Clouds. Clouds are of many shapes and sizes. For convenience in identifying clouds each type of cloud has been given a name. Since clouds occur at varying altitudes, they have been divided into four general families according to their height; namely, Family A—High Clouds; Family B—Middle Clouds; Family C—Low Clouds; Family D—Vertically Developed Clouds.

Family A: Cirrus Clouds

Cirrus (Ci). Cirrus clouds are detached clouds of delicate and fibrous appearance, usually without shading, generally white in color, and often of a silky appearance. Cirrus appears in the most varied forms, such as isolated tufts, lines drawn across a blue sky, branching featherlike plumes, curved lines ending in tufts, and so on. Cirrus is often arranged in bands which cross the sky and which, owing to perspective, seem to converge toward opposite points on the horizon. Cirrus clouds are composed of ice crystals. Except when unusually dense, they are nearly transparent and, as a rule, when they cross the sun's disk they hardly diminish its brightness.

When these clouds are detached from the others and appear light and silky or hazy, they represent a condition of fair weather particularly appealing to the pilot. When they radiate long parallel bands or fan out from a given point above or beyond the horizon, they are a sign of approaching stormy weather.



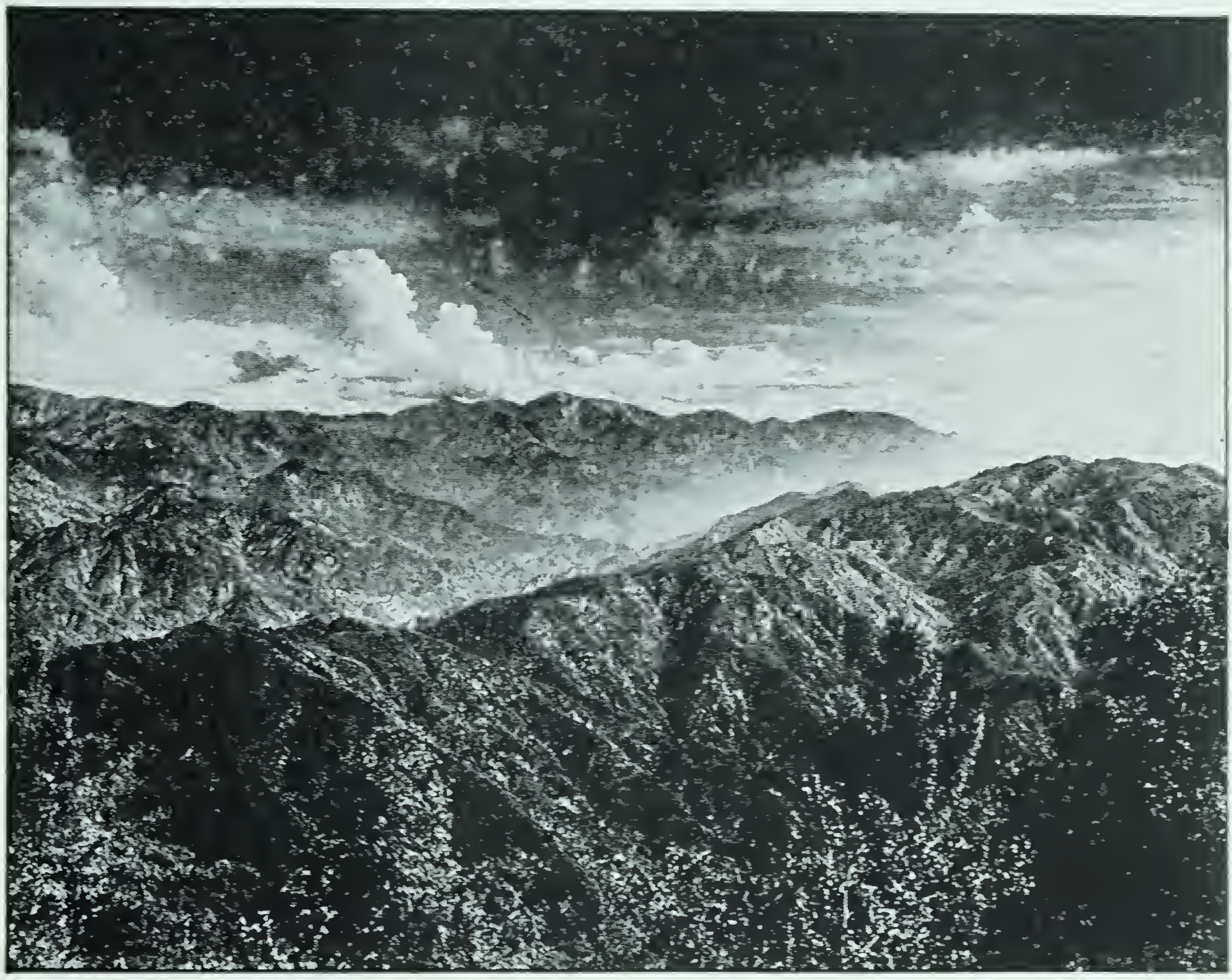
Courtesy U. S. Weather Bureau

Fig. 50. Cirrus: A member of the family of High Clouds

FAMILY B: ALTO-CUMULUS CLOUDS

Alto-cumulus (Ac). Alto-cumulus clouds are composed of layers (or patches) or nearly globular masses. The elements of these clouds are arranged in groups, lines, or waves following one or two directions, and are sometimes so close together that their edges join. The smallest elements of the regularly arranged units may be fairly small and thin, with or without shading. The thin and translucent edges often show irisations, which are rather characteristic of alto-cumulus. A cloud sheet which is continuous, at least over the greater part of the layer, and consists of dark and more or less irregular elements, with sharp relief on the under surface of the sheet, is classed as alto-cumulus rather than alto-stratus.

The alto-cumulus (castellatus) indicates a change from clear to chaotic, thundry skies. Their lower bases are more regularly lined, supporting broken and towering masses extending through a region of unstable air above them. Their towering masses, while interesting and inviting, are warning signs to an airman because of the unstable condition of air currents inside their billowy forms.

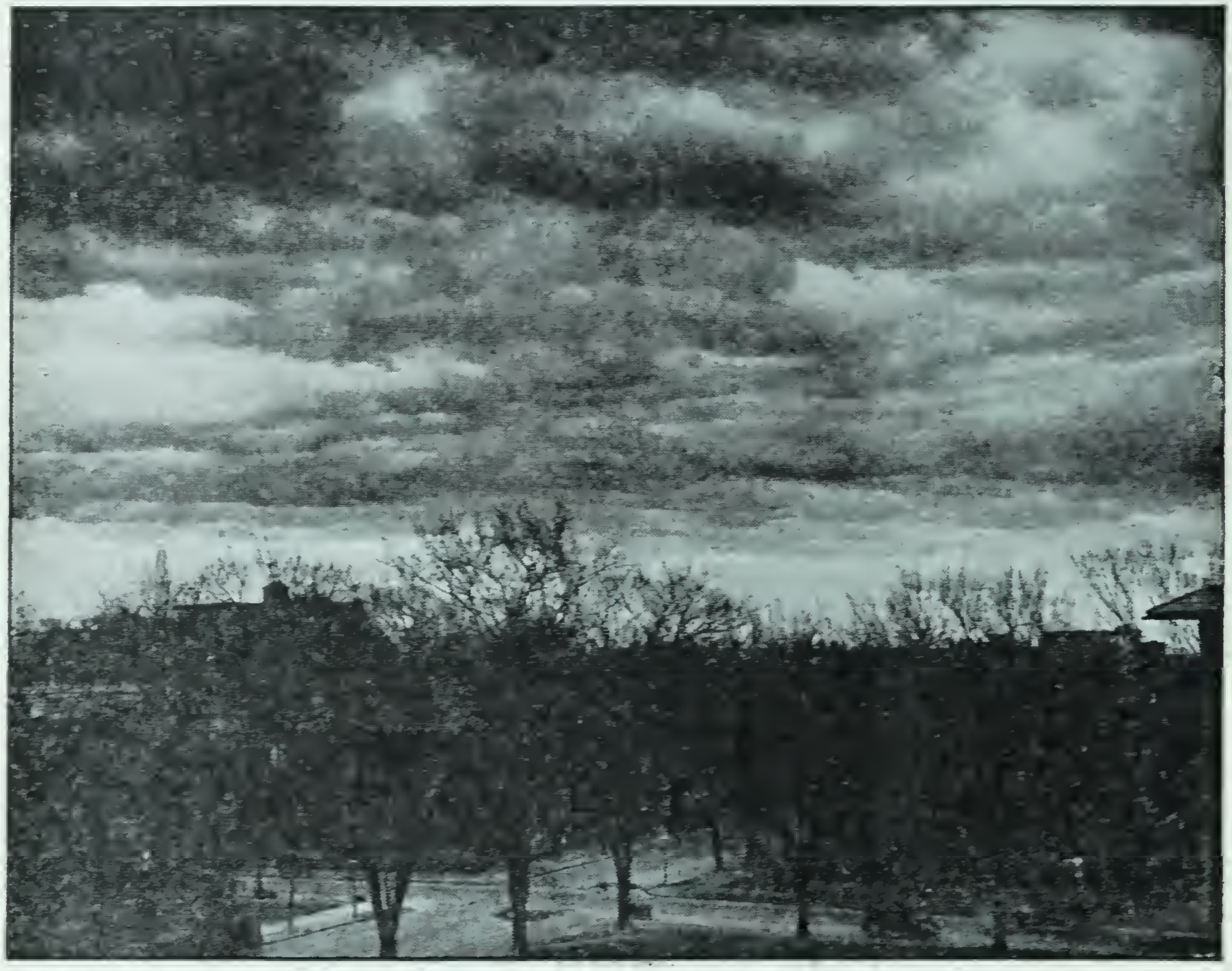


Courtesy F. Ellerman, Mount Wilson Observatory

Fig. 51. Turreted alto-cumulus

FAMILY C: STRATO-CUMULUS

Strato-cumulus. Strato-cumulus clouds consist of large, rolling or lumpy masses of a dull gray color interspersed with open spaces or bright, thin spots. They arrange themselves in regular rows or patterns and resemble the alto-cumulus. They are formed by convectional currents of air, and can be identified by their rounded tops and flat bases at levels where the air is saturated. As a rule, they are not very deep and they cover a considerable area of the sky. If the globular masses expand or swell upward, they resemble the cumulonimbus, and precipitation results.



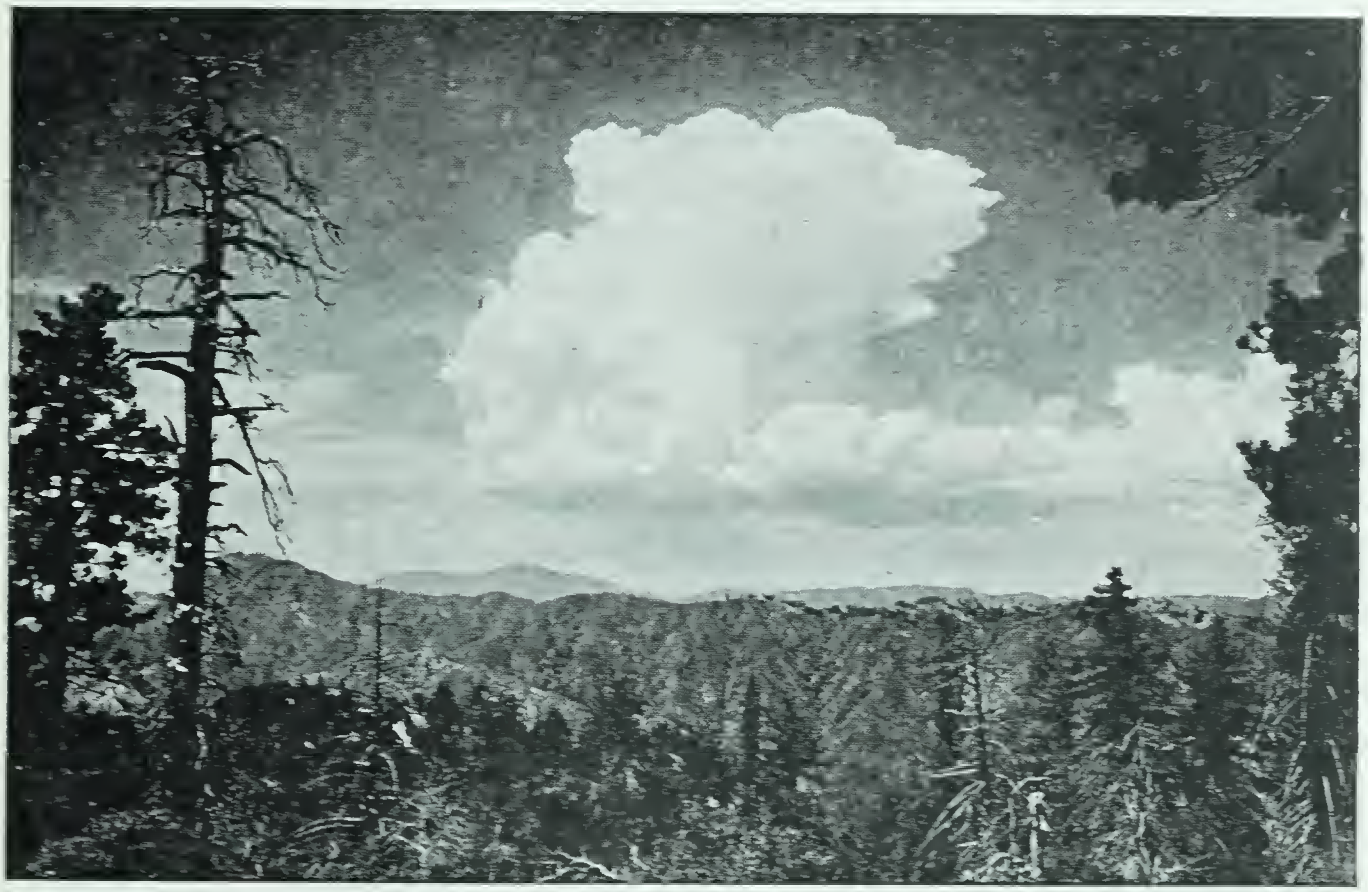
Courtesy W. J. Humphreys

Fig. 52. Strato-cumulus

Family D: Cumulus and Cumulo-nimbus Clouds

Cumulus. Cumulus clouds are vertical developments where the air next to the surface has been heated and forced upward. Their upper surfaces reflect white in the sun, whereas the shaded bottoms are dark and often threatening. Cumulus tops are shifty and in the course of time will develop many and varying patterns, from the well-known cauliflower type to thick, fan-shaped anvil heads.

As these cumulus masses continue to thicken and grow darker they become cumulo-nimbus clouds. They are always present during thunderstorms and are very dangerous to flying. So powerful are the up-drafts within that it is not uncommon to see them rear huge anvil heads well up toward the cirrus levels, and even beyond.



Courtesy American Airlines

Fig. 53. Cumulus and cumulo-nimbus clouds

FOGS

Fogs by radiation. During the day the land surfaces have been increasing in temperature. After the sun has gone down, the heat received during the day is radiated back into the air, cooling the surface. If the earth continues to cool below the temperature of the air, the air in contact with it will cool. If the cooling continues below the dew point, condensation will take place in the form of minute water globules, which, if sufficient in number, become fog. The colder and heavier air settles in valleys and low places, and fog is especially likely to form in these places. A fog of this kind is called a *ground fog.*

Fogs in regions of little or no wind are likely to be thin, but those formed in regions of light winds are likely to be rather deep. If the winds increase to 5 or 10 miles per hour, the warm upper air and cold lower air will be thoroughly mixed. Such mixing prevents or destroys fog.

Along a coastal area, such as Lower California, fogs lift and disappear by a process commonly expressed as *burning-off*. What really happens is that the earth's surface and the air in contact with it increase in temperature during the first two or three hours of the early morning sun and evaporate the fog. What does not evaporate is lifted by convectional currents.

Fogs by advection. Advection fogs occur in all parts of the United States. They are more prevalent along the coasts. Warmed air which moves out over the cooler ocean surfaces forms clouds which are blown back inland in the afternoon and out to sea again at night. Another type of advection fog is caused by warm moist air moving inland over colder surfaces. Particularly is this true in winter.

Advection fogs also form in the Central States in the vicinity of lakes, along river valleys, at mouths of rivers, and in regions where warm moist air passes under layers of cold dry air.

Fogs caused by rain. Rain falling through a mass of cool air in line with an approaching mass of warm air also causes fog.

Precipitation. Precipitation varies from place to place and from time to time. As evaporation from surfaces of ponds, lakes, oceans, and vegetation takes place, the air is being filled with moisture. How much moisture can be mixed with the air depends on the temperature of the air. It was pointed out that more can be present in warm air than in cold air. Therefore, when the air contains all of the moisture possible, it is said to be *saturated*. Should the temperature drop any lower, some of the water vapor will condense into clouds, rain, snow, sleet, or hail, and fall to the earth's surface. The kind of precipitation depends on the temperature of the air and its moisture content. In air of moderate temperature rain will result, but cold air may develop snow, hail, or sleet. In any event, flying is affected by any type of precipitation. Depending on its intensity, rain or snow may prevent flying altogether by obstructing vision. Dangerous areas can be identified by the type of clouds with which they are associated. Hail, a hazard to flying, is often present in cumulo-nimbus clouds, and can do considerable damage to the plane. Sleet, though not so dangerous as hail, is undesirable and should be avoided by the pilot.

Rain. Rain is a form of condensed water vapor. Large amounts of rain cannot fall from a given volume of air unless there is a continual renewal of the supply. Most thunderstorms are local in extent and will cause rain over small areas. Because there is a continual shifting of warm- and cold-air masses and an uneven distribution of water vapor, rain will not fall everywhere at the same time nor in the same quantities. While it is raining in Wyoming or Nebraska, Kansas may be experiencing clear skies. Or one city may be receiving rain while another near by is perfectly dry.

Location with respect to the prevailing winds and associate water sources determines the amount of rainfall which any place is likely to receive. Middle-latitude seacoasts receive more rainfall than do interior regions; likewise lowlands, unless they are on the lee side of mountains, receive more rain than uplands.

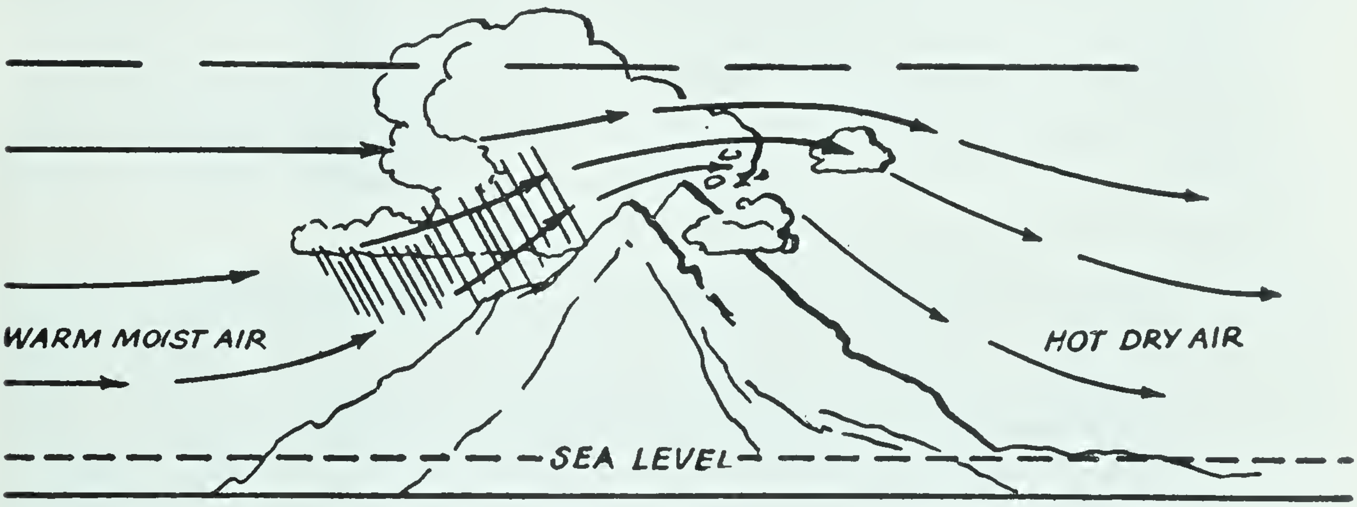


Fig. 54. Precipitation formed orographically

Air forced up the sides of mountains expands, cools, and condenses its moisture into some form of precipitation. This type of precipitation is called *orographic*. The Western Pacific coasts experience this form of rainfall on the windward slopes of the Coast Ranges, the Sierra Nevada, and Cascade Ranges. When this condition exists, continuous sheets of nimbo-stratus clouds move across the mountain peaks and cause steady rain. On the back slope (*lee* or *rain shadow*) of the mountains extreme dry weather, with only occasional rains, is the rule.

Rain also will result when winds from different directions move toward a common center. Near the center, air is lifted to altitudes sufficiently high to cause rain. Thus, it is concluded that precipitation occurs from convectional, orographic, and convergence conditions of the atmosphere.

Hail. Hail results when raindrops are caught in up-drafts and are carried to freezing elevations. After a time down-drafts carry them into lower layers of warm air, where they collect moisture, then are carried back to elevations of snow and freezing. This process continues until the hail has become large and heavy enough to fall to the earth. Hailstorms are usually very destructive and are hazardous to flying. Hail falls only in connection with thunderstorms.

Snow. Snow is another form of precipitation. It is formed when the air becomes suddenly chilled to temperatures below freezing. The water vapor will condense into crystals called snow.

Instruments for measuring moisture in the air. Moisture exists in the air in three forms, namely: (1) vapor; (2) liquid; (3) solid. As a vapor, it is in an invisible state which, under certain conditions, condenses into the liquid of rain, water clouds, and fog. As a solid, it consists of snow, hail, sleet, and ice-crystal clouds.

Instruments have been devised for determining the amounts of moisture in the air. The *sling psychrometer* is used to determine the humidity of the air. It is essentially two identical thermometers fastened to a supporting frame as illustrated.

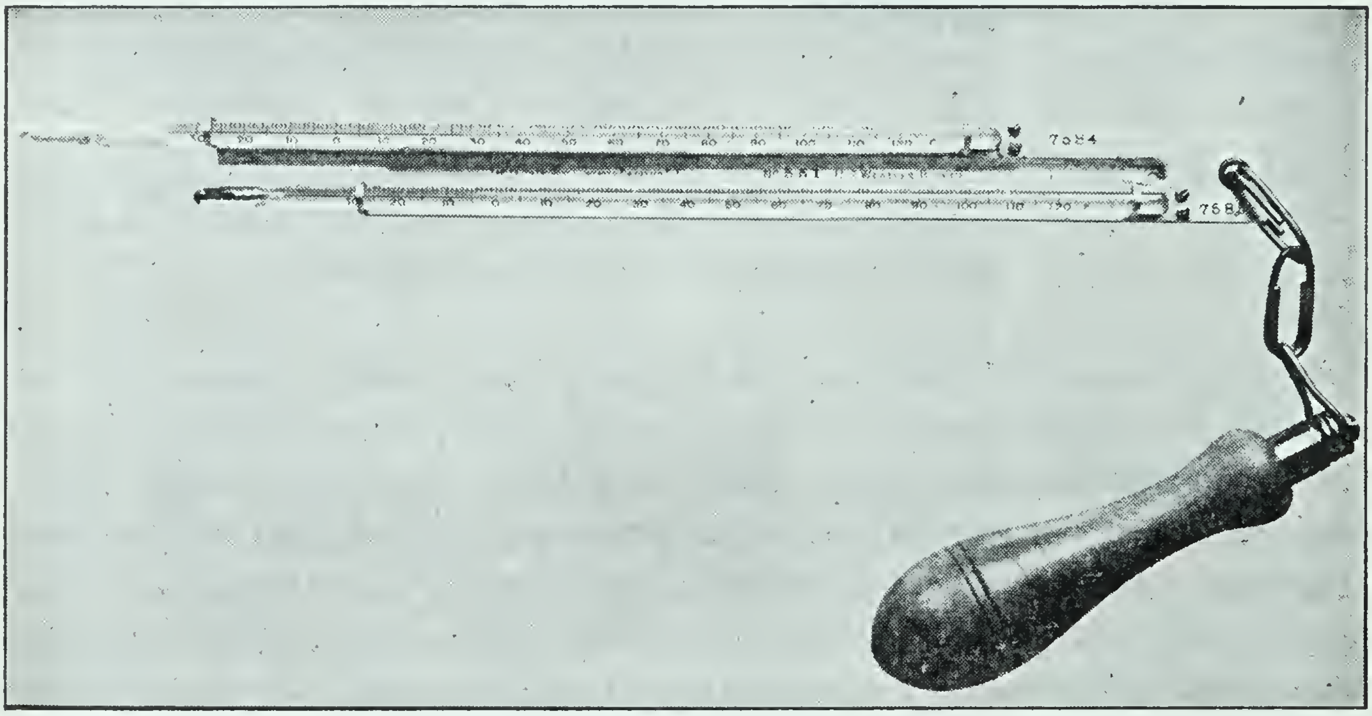


Fig. 55. Sling psychrometer

The mercury bulb of one thermometer is covered with a linen cloth, or jacket, saturated with water. The mercury bulb of the second thermometer is left exposed to the air. An observer now whirls the instruments through the air for a few minutes to evaporate as much moisture from the linen jacket as possible. Then both thermometers are read. The less moisture there is in the air, the greater will be the difference in the reading of the two thermometers.

The more moisture there is in the air, the smaller the variation will be, and if the air is saturated (100 per cent), the readings will be identical.

Laboratory Exercise 46.

Equipment: Two identical Fahrenheit thermometers, linen jacket or cloth, supporting frame or sling psychrometer if available.

Procedure: Read both thermometers before attaching the jacket and record the results. They should read the same. Attach the linen jacket to one of the mercury bulbs. Tie it firmly and saturate with water. Hang the instrument in the air and allow as much moisture to evaporate from the wet bulb as possible. Now read both thermometers and record the results. (The wet bulb should show a lower temperature than the dry bulb unless the air is saturated. The difference in their reading is called a *depression.*) Resaturate the linen jacket and

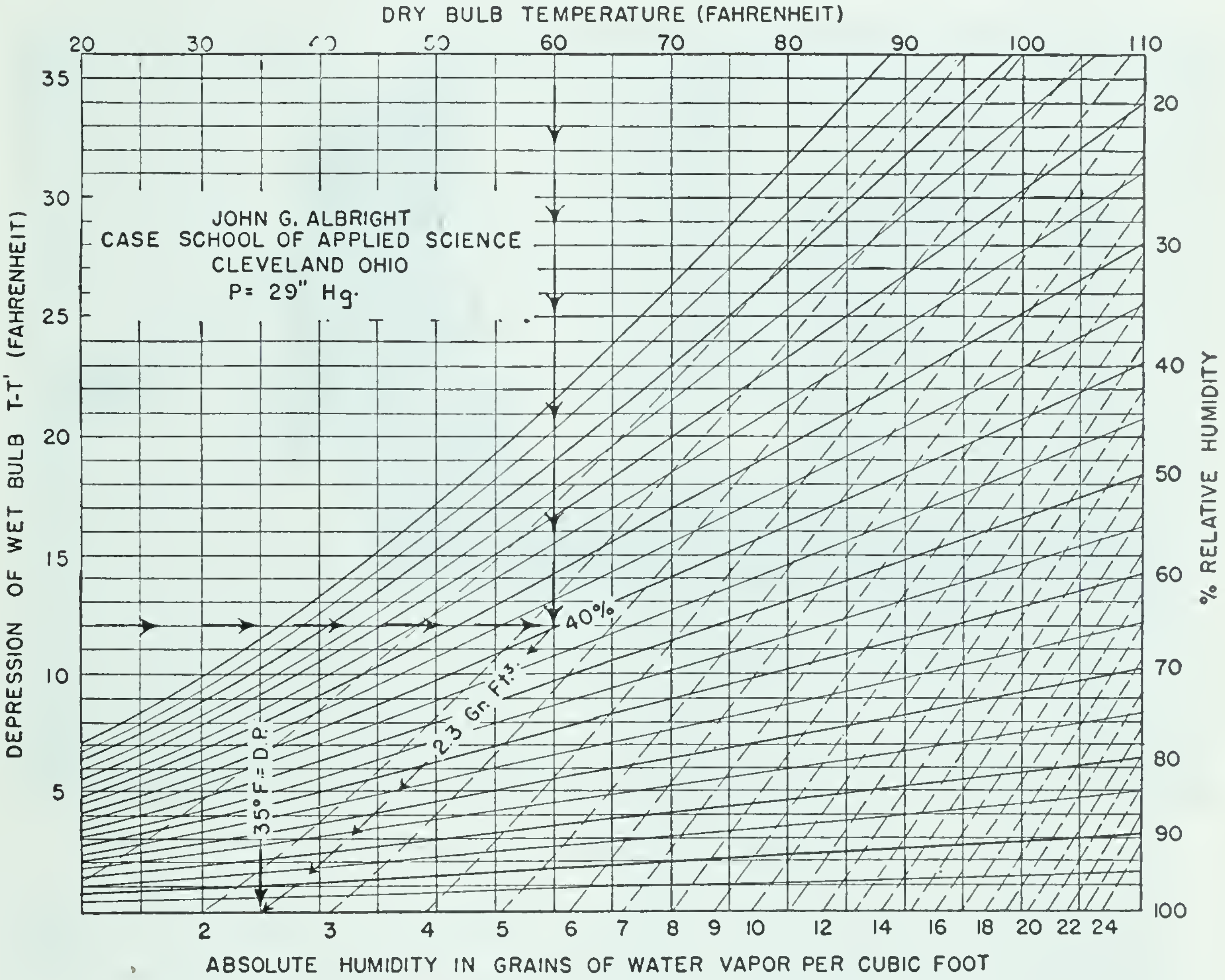


Fig. 56. A chart for computing relative humidity and dew point from a sling-psychrometer reading

whirl the whole instrument for a few minutes to allow the moisture to evaporate. Is there any difference in the readings of the thermometers now? What is the difference? Which one indicates a higher temperature? Why? With the aid of the preceding table, determine what the relative humidity of the air is in the following manner: On the dry-bulb temperature scale at the top of the chart locate the dry-bulb temperature and follow that line down to a point where it intersects the depression line along the left side. (To find the depression point subtract the wet-bulb temperature reading from the dry-bulb temperature reading $d = Db\text{-}Wb$.) Follow the heavy black line to a point on the right margin which shows the per cent of relative humidity. For example, the dry-bulb reading is 60° F. and the wet-bulb reading is 48° F. The depression will be 60° F. — 48° F., or 12° F. The point of intersection coincides exactly with the 40 per cent relative-humidity curve. To find the dew point follow from the point of intersection between the dashed lines to the base, or *absolute humidity in grains of water vapor per cubic foot line.* Note in this case that this line establishes a point at the junction of the base and the 35° F. lines. This figure represents the dew point. How many grains of water vapor per cubic foot are there?

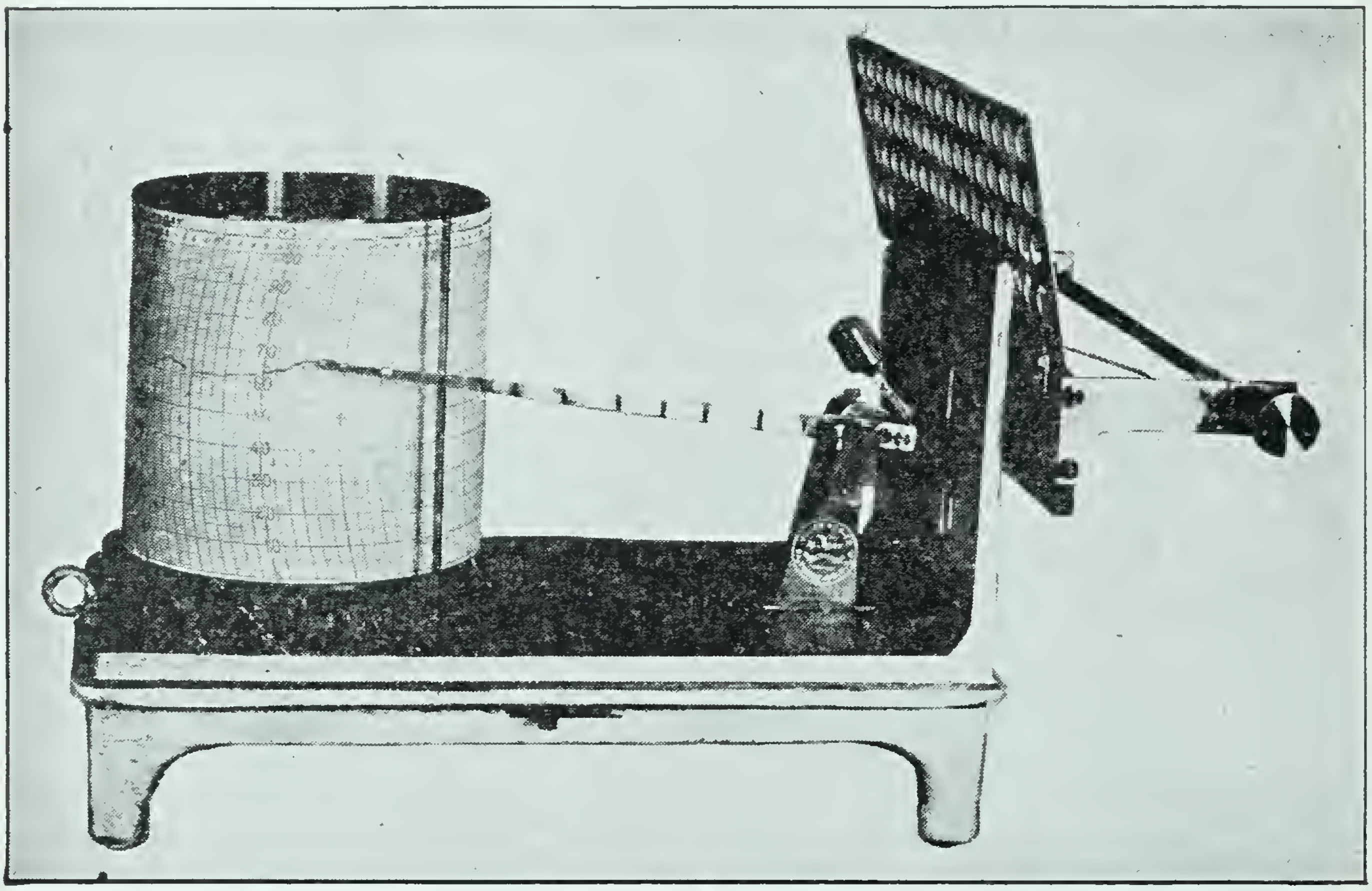


Fig. 57. A recording hair hygrometer

Exercise 47. Find the relative humidity when the dry bulb = 70° F. and the wet bulb = 50° F.

Exercise 48. Find the dew point when the dry bulb = 70° F. and the wet bulb = 50° F.

Exercise 49. Find the absolute humidity when the dry bulb = 70° F. and the wet bulb = 50° F.

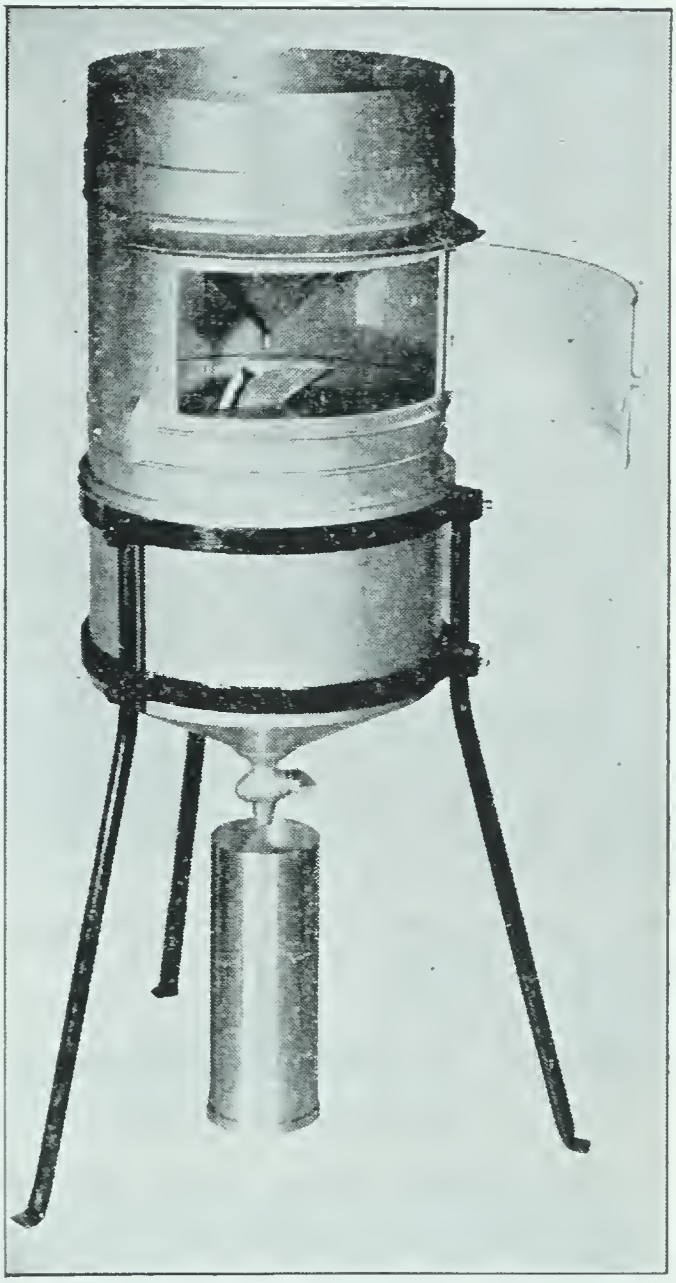
Exercise 50. Find the dry-bulb temperature when the wet bulb = 50° F. and the depression = 20° F.

Exercise 51. Find the wet-bulb temperature when the depression is 15° F. and the dry bulb is 90° F.

Exercise 52. Find the relative humidity when the dry-bulb temperature is 70° F. and the depression is 0° F.

Exercise 53. What is the relative humidity when the dry-bulb temperature is 70° F. and the depression is 0° F.?

Another instrument used in measuring the humidity of the air is the *hygrometer.* It consists of a strand of human hairs which shorten and lengthen according to the humidity of the air. This variation in length actuates a series of levers which record the amount of humidity on a calibrated graph fastened on a revolving drum.



Courtesy Julian P. Friez and Sons

Fig. 58. A tipping-bucket rain gauge

Instruments for measuring rainfall and snow. The rain gauge is used for measuring the amount of rain that has fallen. A straight-sided bucket about 8 inches in diameter exposed vertically to the rain can be used as a gauge by measuring the depth of the water collected by it. The Weather Bureau also uses a device called the *tipping-bucket* (see Fig. 58). It consists of a cylindrical compartment. At its upper end is a

10-inch funnel. Directly beneath the apex of the funnel is a bucket with two compartments so balanced that when a compartment is filled with .01 inches of rain, it tips on its pivoted bearing and exposes the empty compartment to the rain. Each time the bucket is tipped it closes an electrical contact which operates an electrical recorder inside the building.

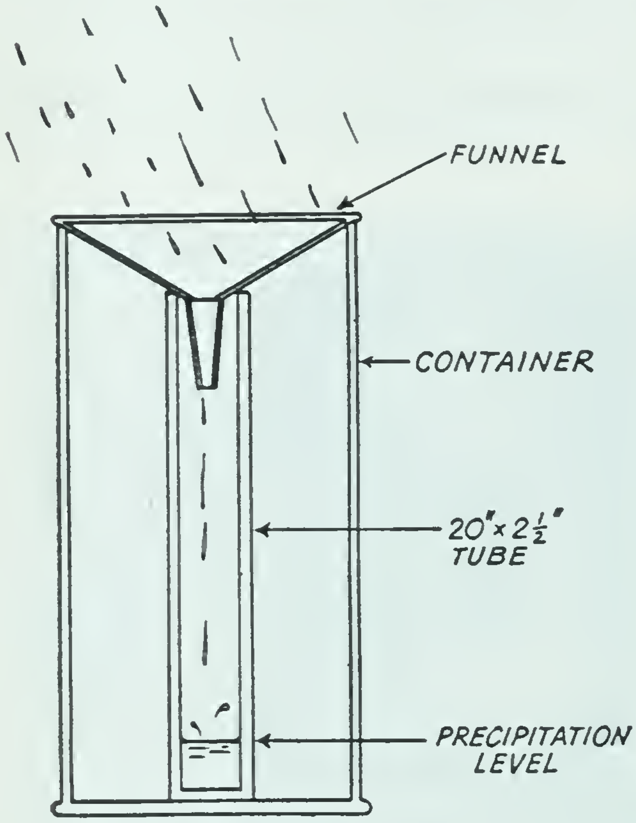


Fig. 59. Rain gauge

Laboratory Exercise 54.

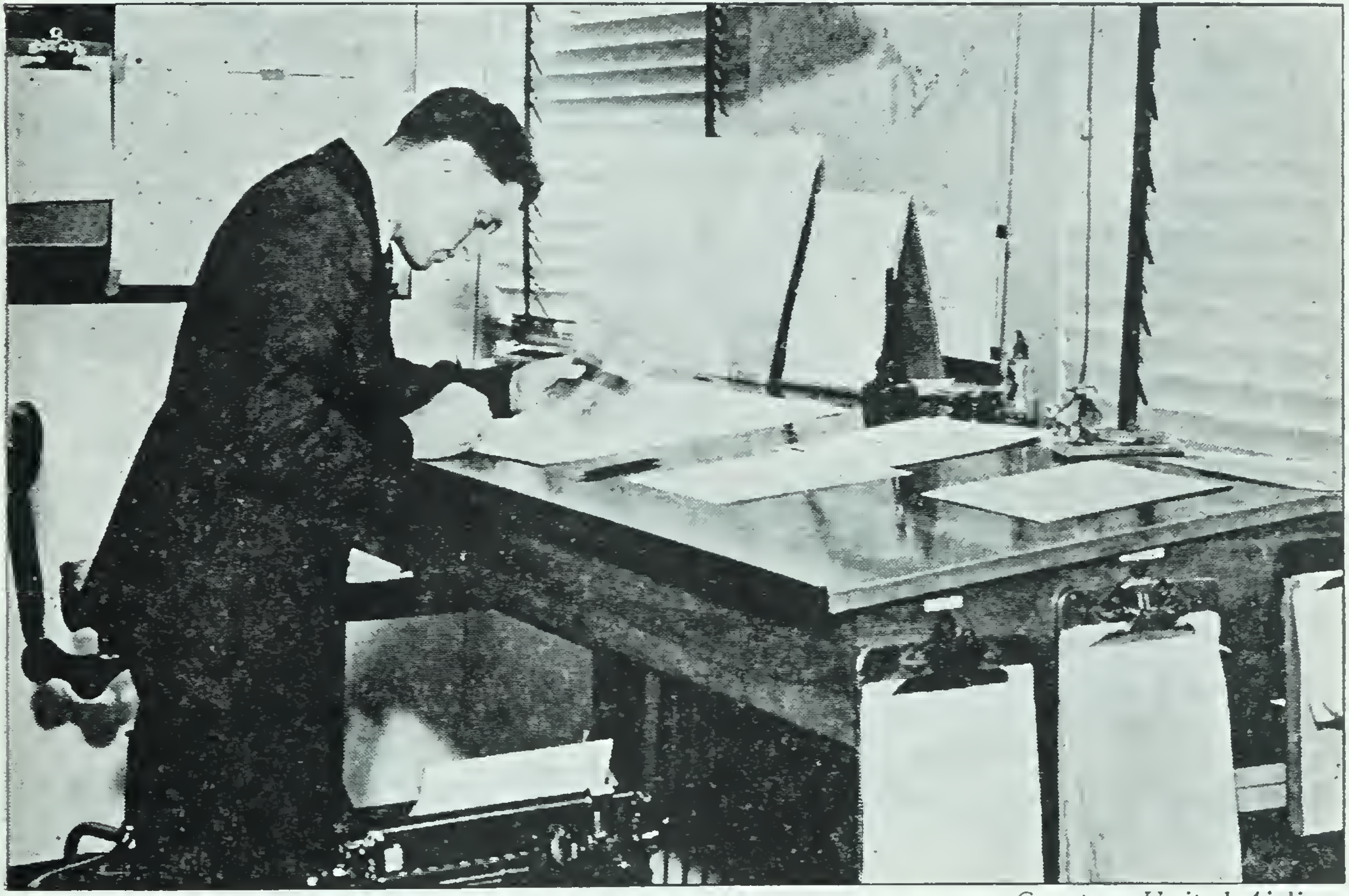
Equipment: 8-inch funnel; 20-inch length of tubing, one end of which is closed and whose inside diameter is 2½ inches; tall bucket or container 8 inches in diameter; measuring stick.

Procedure: Place the tube in the center of the tall container as shown in Figure 59. Place the funnel at the top with its apex directly over the open end of the tube. Place the instrument in the back yard or an open spot away from buildings and trees. The next time it rains remove the funnel, and with a yard rule measure the depth of the water (1 inch = .01 inches of rain). Should it rain sufficiently to overflow the small tube, measure the depth of water in the container (1 inch = 1 inch of rain). This rain gauge is simple to construct and should prove interesting as well as handy.

Problem 4. What knowledge must the air traveler have in order to interpret a weather map and weather forecasts?

Air masses. The plane flies through masses of air. Each mass is of considerable depth and is widespread. It is nearly homogeneous throughout, especially as regards temperature and moisture content. Air masses develop where large portions of the atmosphere come to rest or move slowly over large uniform areas of land or water surfaces. Each mass gradually assumes, to considerable heights, the characteristics which are similar to the surface over which it is passing. For example, great masses of warm air form over the Gulf of Mexico and the Caribbean Sea. In contrast, practically all major cold-air masses in North America form over the cold snow and ice-covered land and water surfaces of the far north. Regions having very little wind are most favorable to the accumulation of both cold- and warm-air masses.

The two general sources of cold- and warm-air masses are the polar and the tropical regions. The air may take its properties from either land or water surfaces.



Courtesy United Airlines

Fig. 60. No guesswork here! Air transport operations have become a highly precise, scientific business, and up-to-the-minute weather reporting is part of the picture. Here a meteorologist works with hourly reports received by telemeter from points along the system and with other reports from off-line points. He makes a weather map which will not only show existing weather conditions, but the trend of weather fronts.

Eventually there is a movement of the cold dry polar masses of air southward and a movement of the warm moist tropical air northward. These moving masses tend to keep their uniform properties even in the upper portions. The surface layers are modified more or less by the land and water surfaces over which they move. Where two air masses meet there is an abrupt change in the properties of the air. Along these fronts important changes in weather occur.

When a stream of cold dense polar air meets a stream of warm light tropical air, they do not mix. Instead, a *front* is established. The cold air, which forms a wedge under the warm air, causes the warm air to rise. This rising air expands and cools, clouds form, and precipitation results.

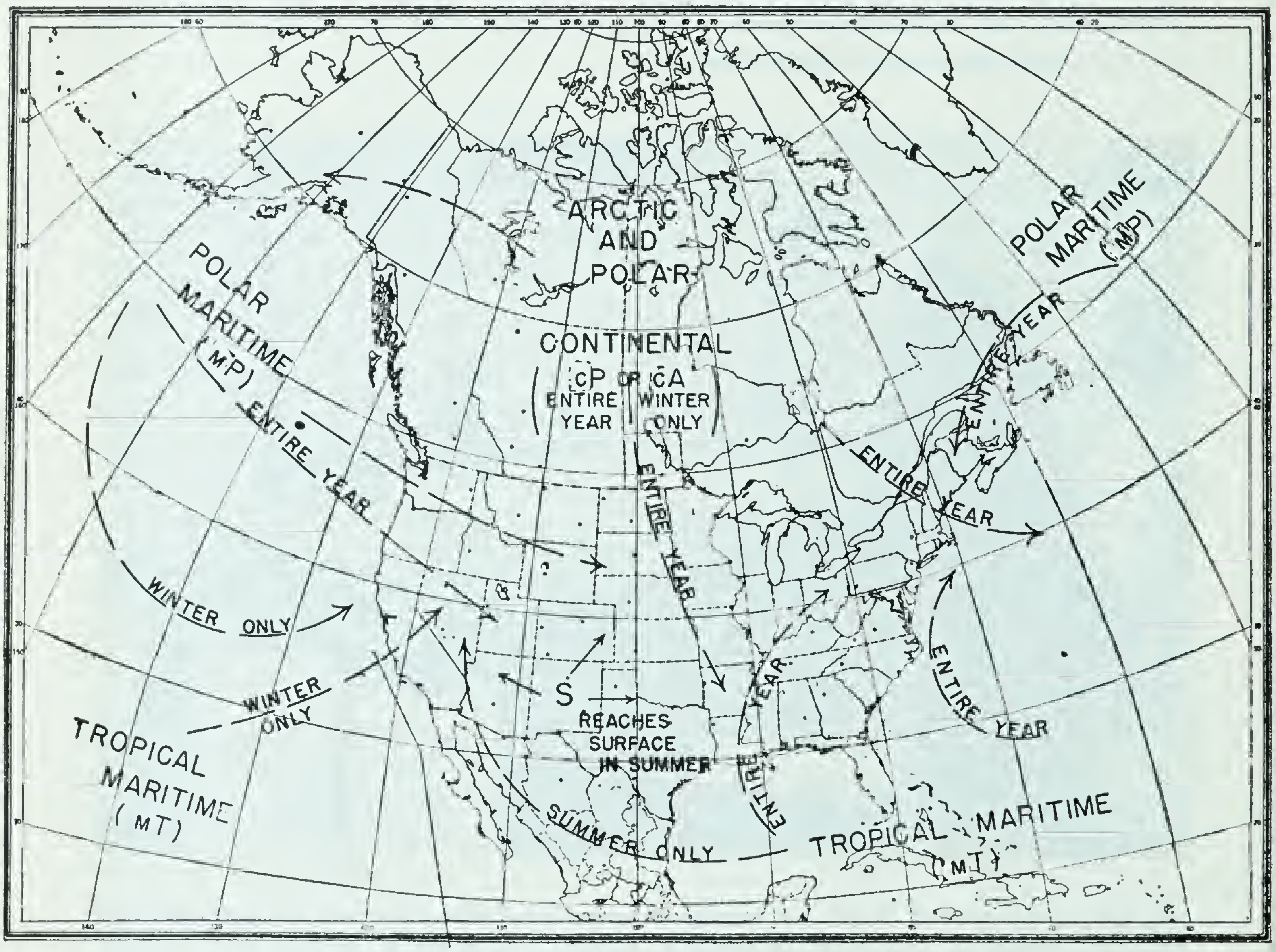
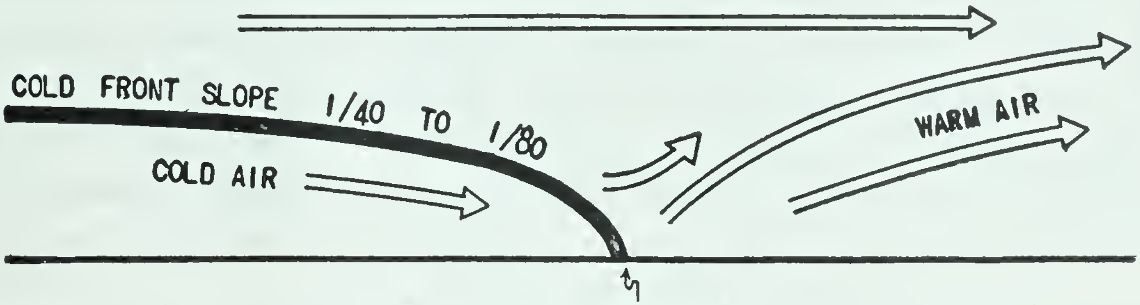


Fig. 61. A map of North America which shows the sources and general movements of the cold and warm air masses throughout the year. Note that each source region is identified by letters.

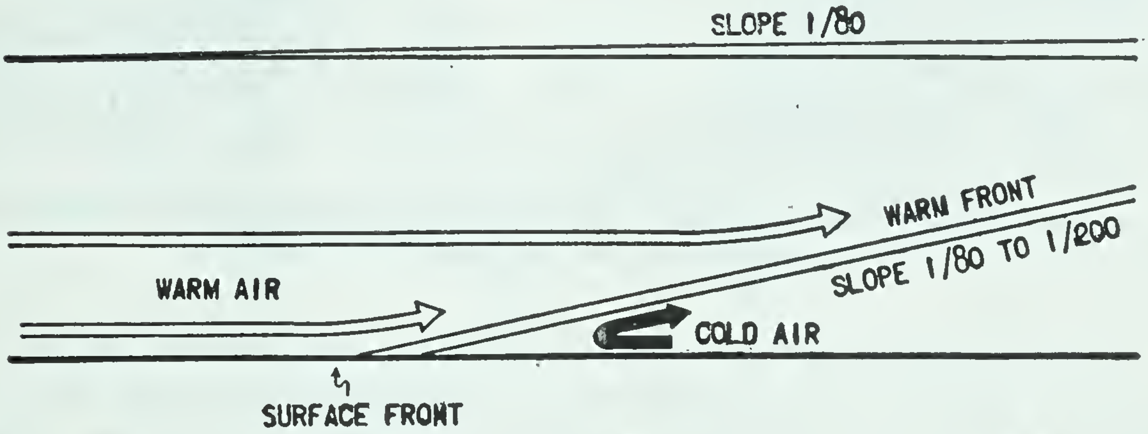
In order to plan a safe journey the air traveler must know where these fronts are apt to be each day. A prominent feature of the new weather map is the symbol which shows weather fronts.

There are four commonly recognized fronts, namely, (1) cold front, (2) warm front, (3) occluded front, and (4) stationary front. The boundary of relatively cold air of polar origin advancing into an area occupied by warmer air of tropical origin is called a *cold front.* The boundary of relatively warm air advancing into an area occupied by colder air is called a *warm front.* The line along which a cold front "overtakes" a warm front is called an *occluded front.* A boundary between two air masses which show little tendency at the time of observation to move either into the warm- or cold-air areas is called a *stationary front.*

Cold-front zones. Some of the most hazardous flying weather is found in cold-front zones. Squall line was the early name given to what is now recognized as an active cold front. This term is still in good use and signifies a belt along which there are heavy rain or snow, low ceilings and poor visibility, severe turbulence, often icing conditions, and frequently thunderstorms. The strong cold fronts are usually oriented in a northeast-southwest direction and move southeast. They are followed by cooler and drier weather, often preceding severe cold spells and sometimes dust storms.



A. COLD FRONT (VERTICAL SECTION)



B. WARM FRONT (VERTICAL SECTION)

Fig. 62. A. Diagram which shows a mass of cold air wedging itself under a mass of warm air. The upper surface of the wedge is the *cold-front slope.* The boundary where the cold-front slope intersects the earth's surface is the *cold-surface front.*

B. Diagram which shows a mass of warm air flowing up and over a slower moving mass of cold air. The boundary where the mass of warm air makes contact with the mass of cold air at the earth's surface is the *warm-surface front.*

There are two general types of cold fronts, slowly moving and rapidly moving cold fronts. These types often change gradually from one to the other so that any differentiation during the intermediate stages must be arbitrary.

Slowly moving cold fronts. There is a general upsliding motion of the warm air along the frontal surface and the formation of a rather broad, postfrontal alto-stratus and nimbo-stratus cloud system in the warm air when it is stable. Stratiform clouds may form in the warm air several miles ahead of the surface front. If the warm air is conditionally unstable, cumulo-nimbus clouds and frequently thunderstorms develop. There may even be enough upward movement in the cold air to form low stratiform clouds. (See Fig. 63.)

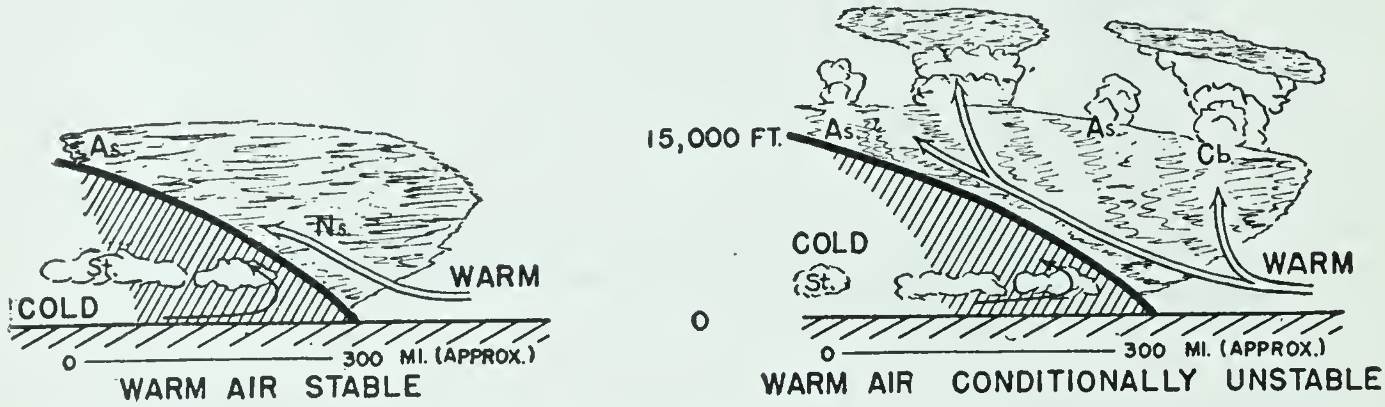


Fig. 63. Cold front (vertical section). The diagram illustrates what happens when the air masses are in an unstable condition.

The determination of the stability, ice-crystal level, and level of free convection of the warm air is important because the wedge of cold air may not be thick enough to lift the stratiform clouds to the rain-forming level or high enough to allow the instability of potentially unstable warm air to be released. The stability of the air may be determined from soundings or the type of clouds present. All towering cumuliform clouds indicate instability.

Fast-moving cold fronts. The motions in this cold front combine downward movement above and below the frontal surface with upward movement in the warm air ahead of the front, as shown in Figure 64. This is the most important type of cold front, is easily located on the weather map, and causes very hazardous weather. The main features of a fast-moving cold front are as follows:

1. Cloud systems that may extend more than one hundred miles ahead of the front.
2. Rapid clearing after the frontal passage.
3. Tendency to dissolve near the ground.

4. An almost continuous line of thunderstorms along the front, and scattered thunderstorms and showers ahead of the front when the warm air is conditionally unstable and moist.

5. Gusty, turbulent surface winds behind the front.

6. A steep frontal edge in contrast to the slowly moving cold fronts which have a relatively flat frontal edge.

Warm fronts. Warm fronts are characterized by both stable and unstable air movements. The air from the warm sector, as shown in Figure 65, gradually moves up over the sloping warm-front surface and forms a broad prefrontal cloud system of stratiform clouds if the air is stable, and of both stratiform and cumuliform clouds if the warm air is potentially unstable. As illustrated in Figure 65, the sequence of cloud types from the warm sector out over the frontal surface to clear air is nimbo-stratus, alto-stratus, cirro-stratus, and cirrus. If the air is convectionally unstable, cumulo-nimbus and alto-cumulus clouds, and frequently thunderstorms will be scattered ahead of the warm front. The precipitation that falls from the cloud system usually starts gradually and increases, then continues evenly until the passage of the system. When cumulo-nimbus clouds develop, the warm-front precipitation will become spotty in character with much heavier rain or snow in scattered areas beneath the cumuliform clouds.

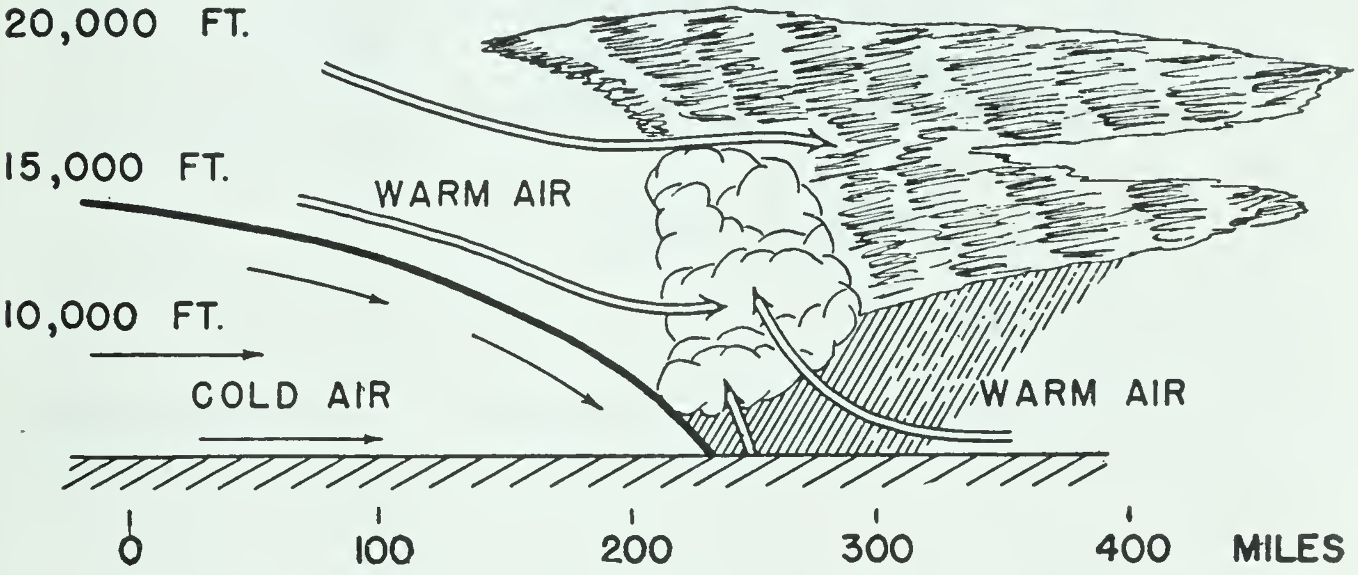


Fig. 64. Vertical cross section through a fast moving cold front

The speed of warm fronts is usually a little above half that of cold fronts, and they usually are not so well marked as the cold fronts because the warm rain heats and moistens the cold air through which it is falling. The physical characteristics of the cold-air mass may be greatly altered in a comparatively short time through the modifying effect of a warm-front rain.

The wide precipitation area ahead of a warm front often contributes to serious aviation hazards in the form of low ceiling and visibility. The humidity of the cold air is raised to near saturation by the rain and then, after the sun sets, additional cooling plus any upslope motion or convergence may "fog in" thousands of square miles. The frontal zone itself may cause zero ceiling and visibility over a wide area.

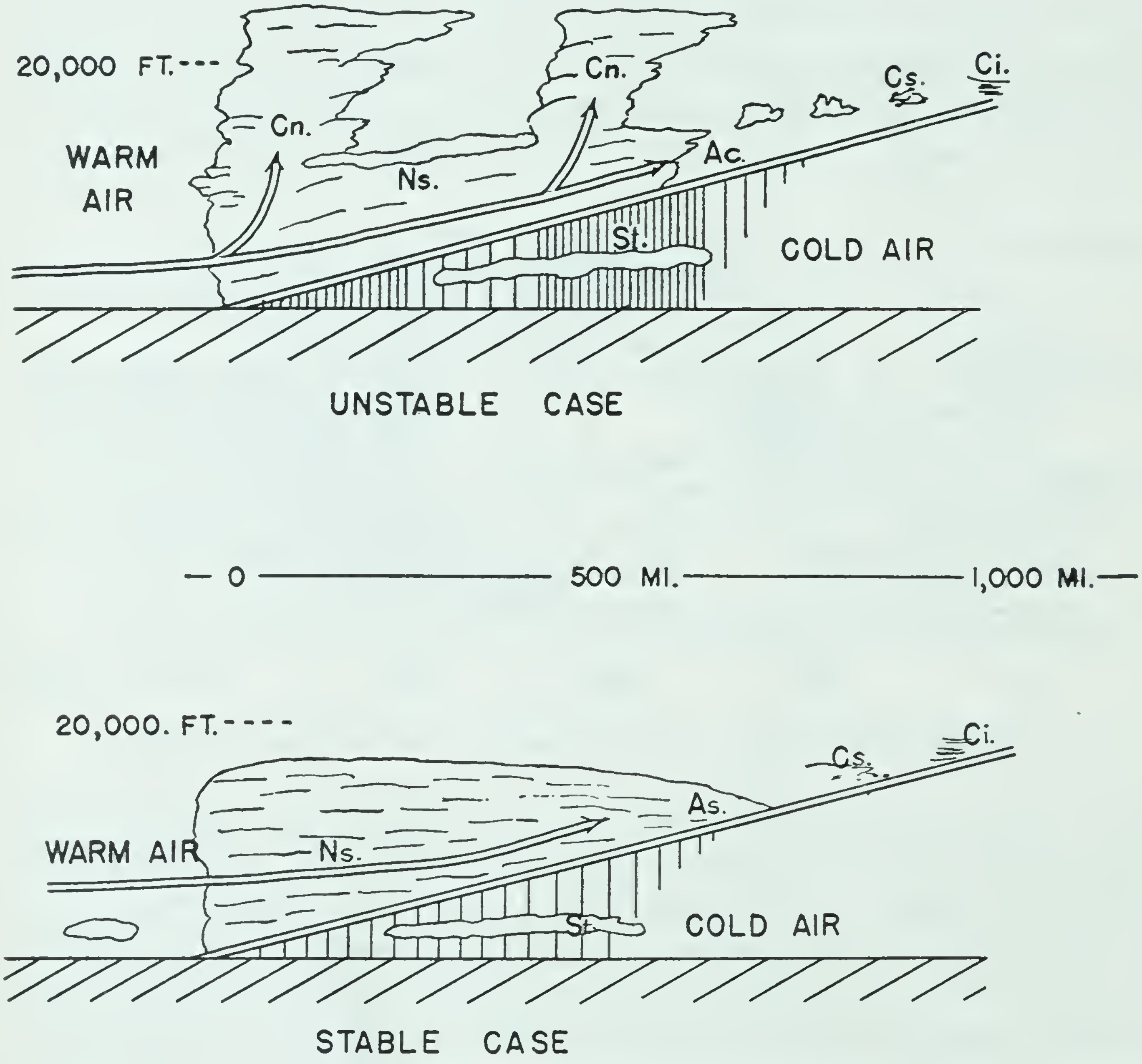


Fig. 65. Warm front cloud systems

Very cold air underneath a warm front is resistant to displacement and may force the warm air to move over a thinning wedge with waves in the upper surface. This gives the effect of secondary upper warm fronts and may cause parallel bands of precipitation at unusual distances ahead of the surface warm front. Some of these upper warm fronts may reach down to the surface and give two or more parallel warm fronts at the surface.

Secondary warm fronts are also formed by returning polar air that has had varying amounts of time over a warm surface, such as the Gulf of Mexico. This type of air has a high degree of potential instability and is quite dry aloft. Low ceilings and visibility frequently occur along the weak fronts formed.

Life cycle of cyclones. North America is never free of cyclonic storms. Such storms form where a cold-air mass contacts a warmer-air mass. Along this contact front the cold air forces itself under the warm air in the form of a thin wedge and the boundary swings northward. The cold air which is moving faster than the warm air begins to spiral in a counterclockwise direction, much as whirlpools develop in a stream between adjacent currents of water moving at different speeds.

The first step in the development of the cyclone is the bending of the front. The cold air which has wedged itself under the warm air is moving faster than the warm air. This wedge of cold air continues to bend the front in a counterclockwise direction until it has completed its circular path. Thus a *low* is formed at the closed end of the warm sector. The cold air forces the warm air upward and completely displaces the warm air.

The aeronautical weather map shows the general movements of air masses and the behavior of weather along the front. It is possible to follow the development of a cyclone (areas of low pressure) by making a study of the movements of air masses across the United States for a period of one week.

The life cycle of the cyclone is shown diagramatically in Figure 66. The student should study carefully the six illustrations and their accompanying descriptions.

Figure 67 shows a plan and two vertical sections of an ideal cyclone. The three illustrations and their accompanying explanations should be studied carefully.

Minor disturbances. The passage of a wind-shift line is a real hazard to flight. This wind-shift line is associated with air-mass fronts. A change in wind direction occurs with both the warm and cold fronts. The shift of the wind is more pronounced, however, with cold fronts.

Wind-shift lines may be accompanied by strong gales, heavy

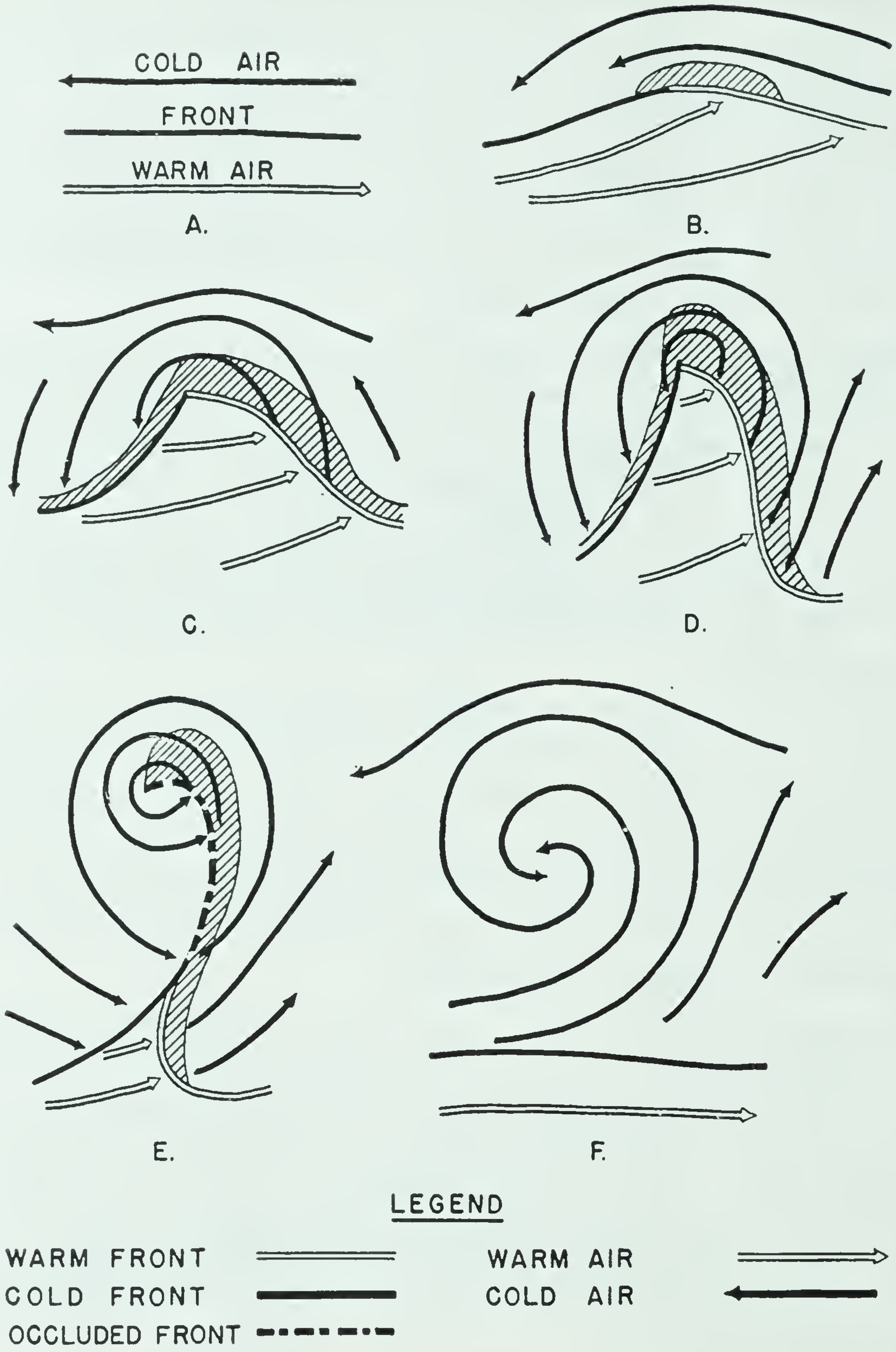


Fig. 66. Life history of a wave cyclone. A. A *front* occurs where a cold air mass and a warm air mass contact each other. B. The cold air, which moves more rapidly than the warm air causes the front to bend, and the first signs of clouds, caused by the rising air, appear. C. The cold air continues to bend the front and forces a wedge under the warm air, thus causing the warm air to rise, more clouds to form, and possible showers or other form of precipitation to occur. D. The cold air continues its circular path and forces its wedge still further under the warm air, thus causing still more clouds and continued precipitation. E. The cold air has succeeded in lifting nearly all of the warm air above the surface. The rising warm air spirals into the upper atmosphere in a counter-clockwise direction, an *occluded* front is formed and the amount of precipitation diminishes. F. The cold air has succeeded in lifting completely, the warm air from the land surface, and thus the cyclone is destroyed.

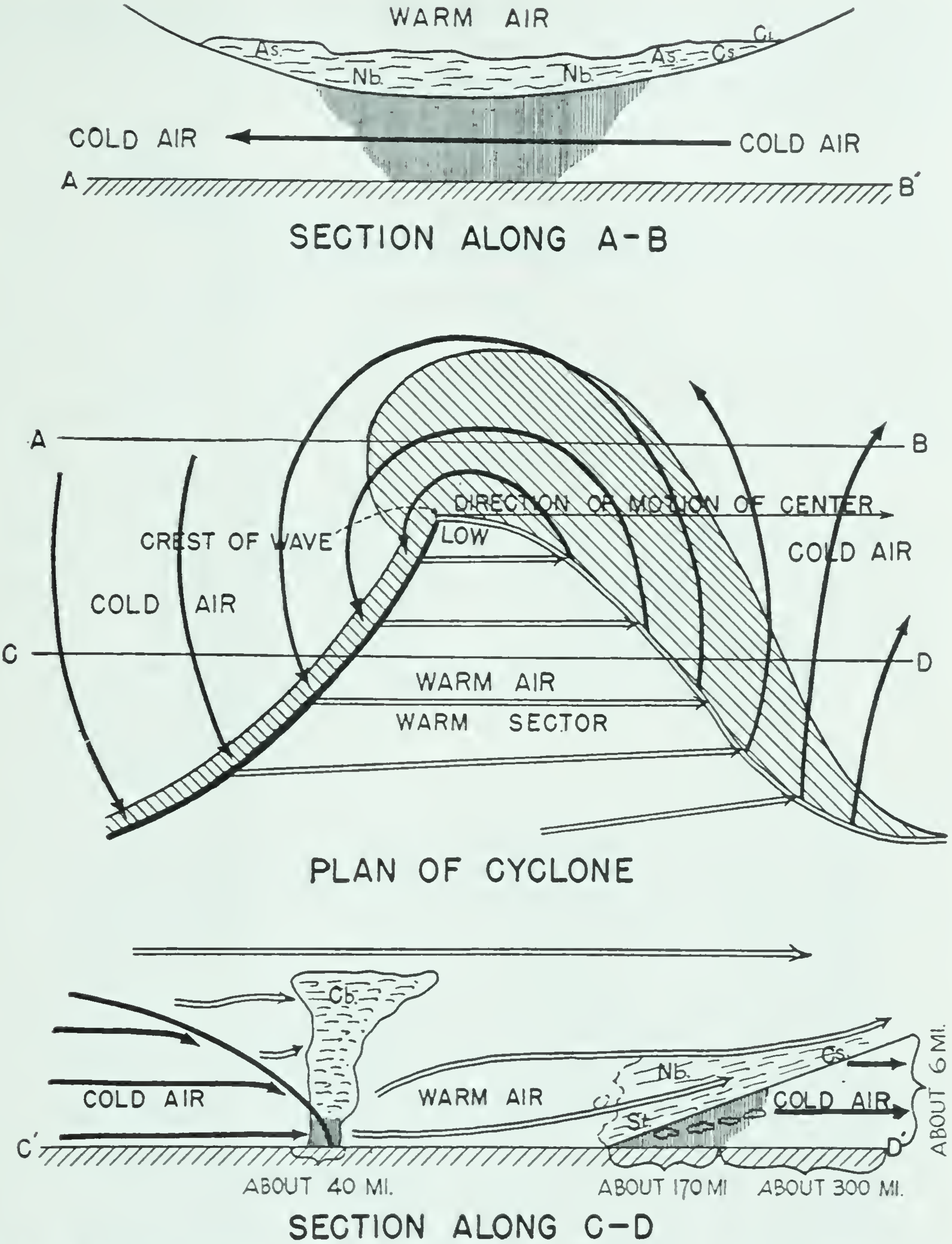


Fig. 67. Cyclonic model. *Top section.* The top section of the illustration shows the elevated warm air mass resting on the cold air mass. The warm air mass, at its present elevation, has cooled, clouds have formed, and precipitation is occurring. This section shows weather conditions as they would exist in a storm area in the position that line A B takes in the diagramatic plan of the cyclone. *Bottom Section.* The bottom section of the illustration shows three types of weather which characterize the cyclone. First, a severe, short-lived storm forms along the cold front. It consists of rather severe vertical air currents which contain cumulus and cumulo-nimbus clouds, from which heavy precipitation is falling. Second, clear weather with possible, intermittent showers are associated with the warm air in the region between the two fronts. Third, in the vicinity of the warm front, less turbulent air currents exist, resulting in showers of longer duration over a larger land area, falling from the nimbus and stratus clouds.

rains, hail, snow, or sleet. In some instances dry wind shifts occur. These are accompanied by strong winds and considerable dust. All of these factors are dangerous to flight.

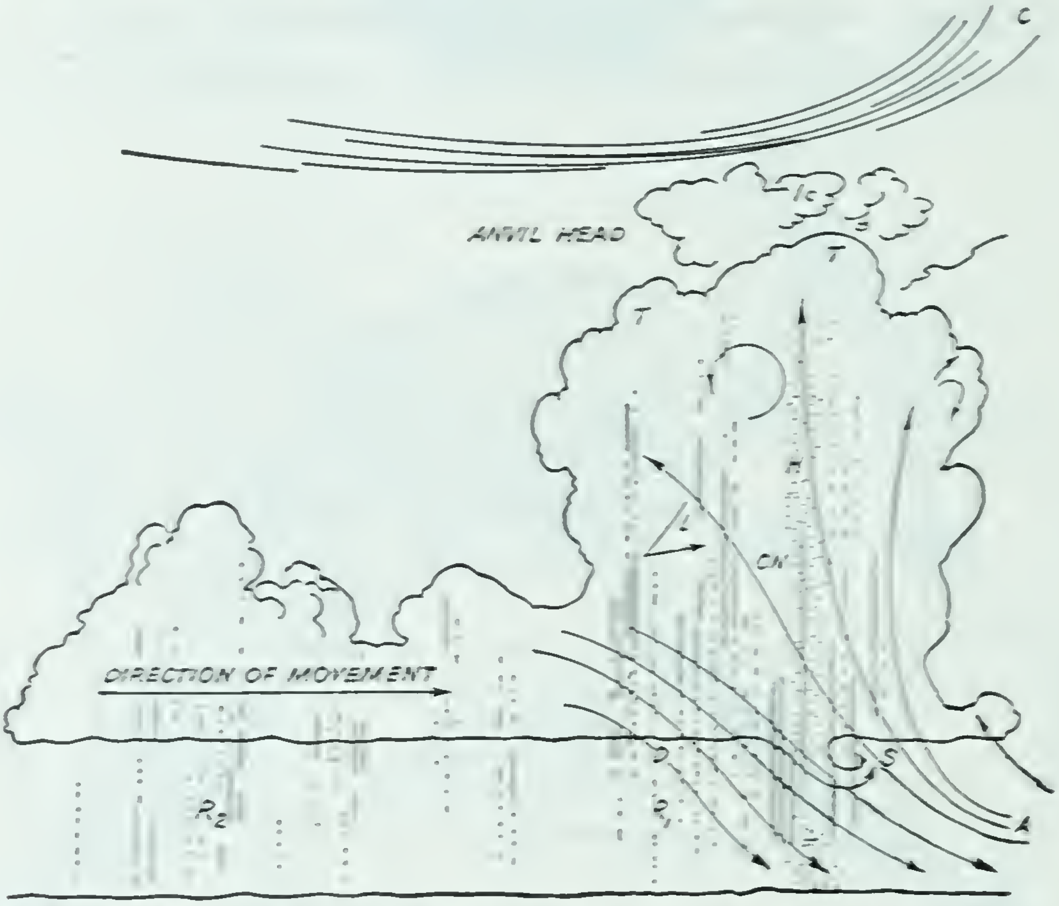


Fig. 68. A vertical section through a typical thunderstorm. At *A* the warm air is rising up into the large mass of cumulonimbus clouds *CN*. Toward the upper part of *CN* the temperature is below freezing and hail *H* is formed. *T* represents the wall limits of nodes called thunderheads. Above the front cumulo-nimbus is the anvil head formed of small ice and snow crystals *IC* above which, at still higher altitudes, there may or may not be cirrus clouds *C*. Lightning *L* may occur at any point in the storm head, causing thunder. From the forward mass rain R_1 is falling at a very rapid rate, and is possibly accompanied by hail. Descending air *D* is blowing through the rain, and is causing a roll *S* in the under side of the cumulonimbus. This roll is known as *scud*, or fracto-cumulus, and is dangerous to flying. If developed sufficiently it might tip vertically like a funnel and develop a tornado. Rain is still falling at R_2, but is beginning to diminish because the temperature is becoming more stable resulting in less condensation. Such storms are less extensive over a cold front. If it is impossible to fly around, above, or below a thunderstorm, the pilot should keep his plane on the ground.

Weather stations keep commercial pilots informed at all times of the changing wind direction and its behavior. The amount of shift is frequently great enough so that a radical change in the heading of the plane is necessary in order to arrive at the desired destination.

Thunderstorms. Thunderstorms are about the same in all parts of the world. On any summer day when the earth is heated sufficiently to cause convectional currents clouds will form in the updrafts and, if lifted high enough, condensation will take place and rain will fall. (See Fig. 68.)

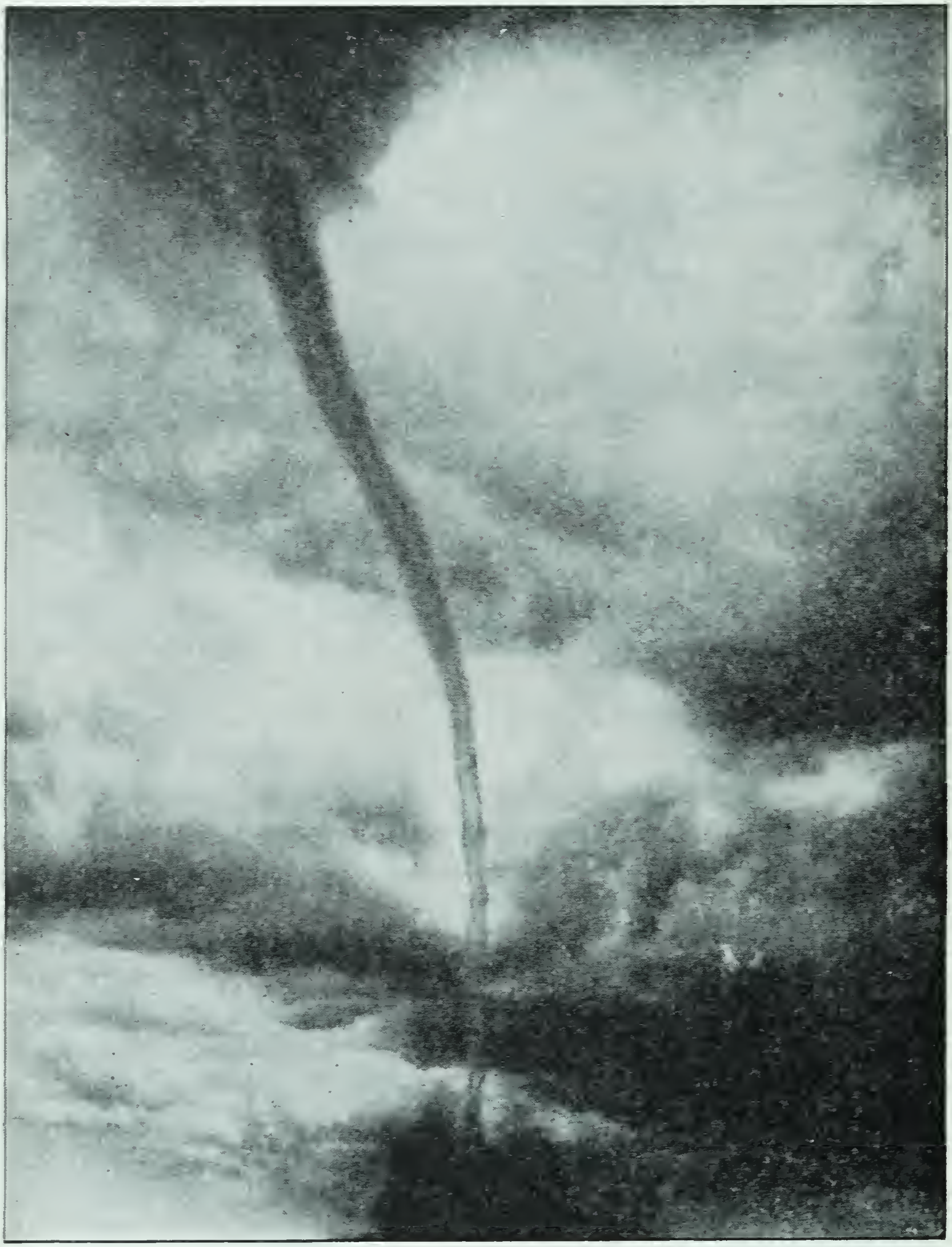
The tornado. One of the most violent storms is the *tornado.* It consists of a rapidly whirling, funnel-shaped vortex, usually accompanied by rain and sometimes by hail. It varies in size from a few hundred feet to a few hundred yards, and rarely travels more than between 20 and 30 miles. Tornadoes occur with greater frequency over Central United States and rarely in higher latitudes. Fortunately, they are short-lived and can usually be seen in time to be avoided. The pilot needs only to avoid them.

Tornadoes are probably started by some unstable condition of the air in a thunderstorm. It is also believed that they result from a roll cloud bending toward the earth's surface near a cold front where the atmospheric disturbance (because of the abrupt temperature changes between the cold-air mass and the warm-air mass) is the most abrupt.

The center of the vortex (funnel) has a lower atmospheric pressure than the outside area, which is caused by centrifugal force within the rapidly whirling mass. (The velocity of wind around the vortex may exceed 300 or 400 miles per hour. Objects in the path of a tornado will be destroyed, and considerable loss of property will result. (See Fig. 69.)

Hurricanes. Storms that cover considerable areas and develop intense cyclonic disturbances of tropical origin are known as *hurricanes.* They are accompanied by high-velocity winds gyrating around a broad central area of low pressure. Winds which characterize hurricanes are very often strong and often attain velocities of more than 200 miles per hour. They do not as a rule travel far inland, and when they do cross the coast they are usually completely broken up within a period of one or two days. Flying through a hurricane is impossible.

Ice formation. Icing is one of the aviator's worst enemies. The accumulation of ice on an aircraft decreases the lifting ability of a wing; jams the controls, often making them uncontrollable; cuts the velocity of the plane by deforming the propeller contour and decreasing its thrust; causes severe and even destructive vibrations by the uneven breaking-off of ice from the propeller; and adds con-



Courtesy Gale and Wright

Fig. 69. A fully developed tornado. Observe the dark clouds above the long, slender vortex. Note also the clearly defined sides of the whirling mass. By observing carefully it may be possible to note that the mass is whirling in a counterclockwise direction. The lower end of the funnel has reached the earth as is evidenced by the bowl of dust near the surface. (This tornado lasted only a short time and did little damage to property.)

Courtesy Western Air Lines

Fig. 70. Scientific Flight Planning. An hour before every Mainliner flight, the pilots and dispatcher get together to lay out a scientific and precise plan for the plane's operation. In such conferences, latest weather reports figure prominently. Before a plane is dispatched the Mainliner captain and dispatcher must agree in writing that conditions are flyable.

siderable weight to the plane. Engine power is also decreased because of the formation of ice in the carburetor.

Icing results when water vapor is changed to a liquid that then freezes on the surfaces and structures of the plane. Two types of ice form on the plane, namely, clear ice and rime ice.

1. Clear ice is very hard and transparent. It forms at temperatures 32° F. or below. However, about 80 per cent of it forms be-

tween 10° F. and 32° F. It forms a blunt surface on the leading edge of the airfoil and plane structures, producing more resistance to forward motion in the air, thus causing the plane to lose considerable speed.

2. *Rime ice* is opaque and does not cling to the airfoil surfaces or structures as persistently as clear ice. It is easily broken loose from wing and tail surfaces by de-icers. However, it tends to adhere to the wing's surface just back of the de-icer and increases the stalling speed of the plane.

In general, both clear and rime icing occur on a plane. Maximum icing conditions occur in regions where there are strong vertical air currents and the temperature is below freezing.

Icing which occurs in carburetors is explained in Unit IV.

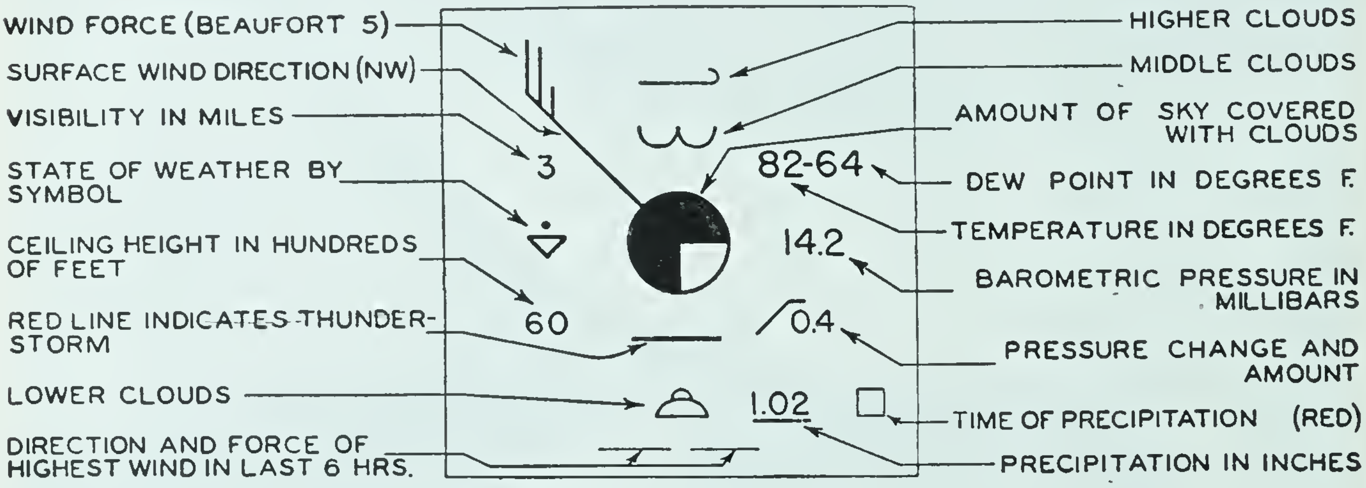

WIND FORCE (BEAUFORT 5)
SURFACE WIND DIRECTION (NW)
VISIBILITY IN MILES
STATE OF WEATHER BY SYMBOL
CEILING HEIGHT IN HUNDREDS OF FEET
RED LINE INDICATES THUNDERSTORM
LOWER CLOUDS
DIRECTION AND FORCE OF HIGHEST WIND IN LAST 6 HRS.
3
60
82-64
14.2
0.4
1.02
HIGHER CLOUDS
MIDDLE CLOUDS
AMOUNT OF SKY COVERED WITH CLOUDS
DEW POINT IN DEGREES F.
TEMPERATURE IN DEGREES F.
BAROMETRIC PRESSURE IN MILLIBARS
PRESSURE CHANGE AND AMOUNT
TIME OF PRECIPITATION (RED)
PRECIPITATION IN INCHES

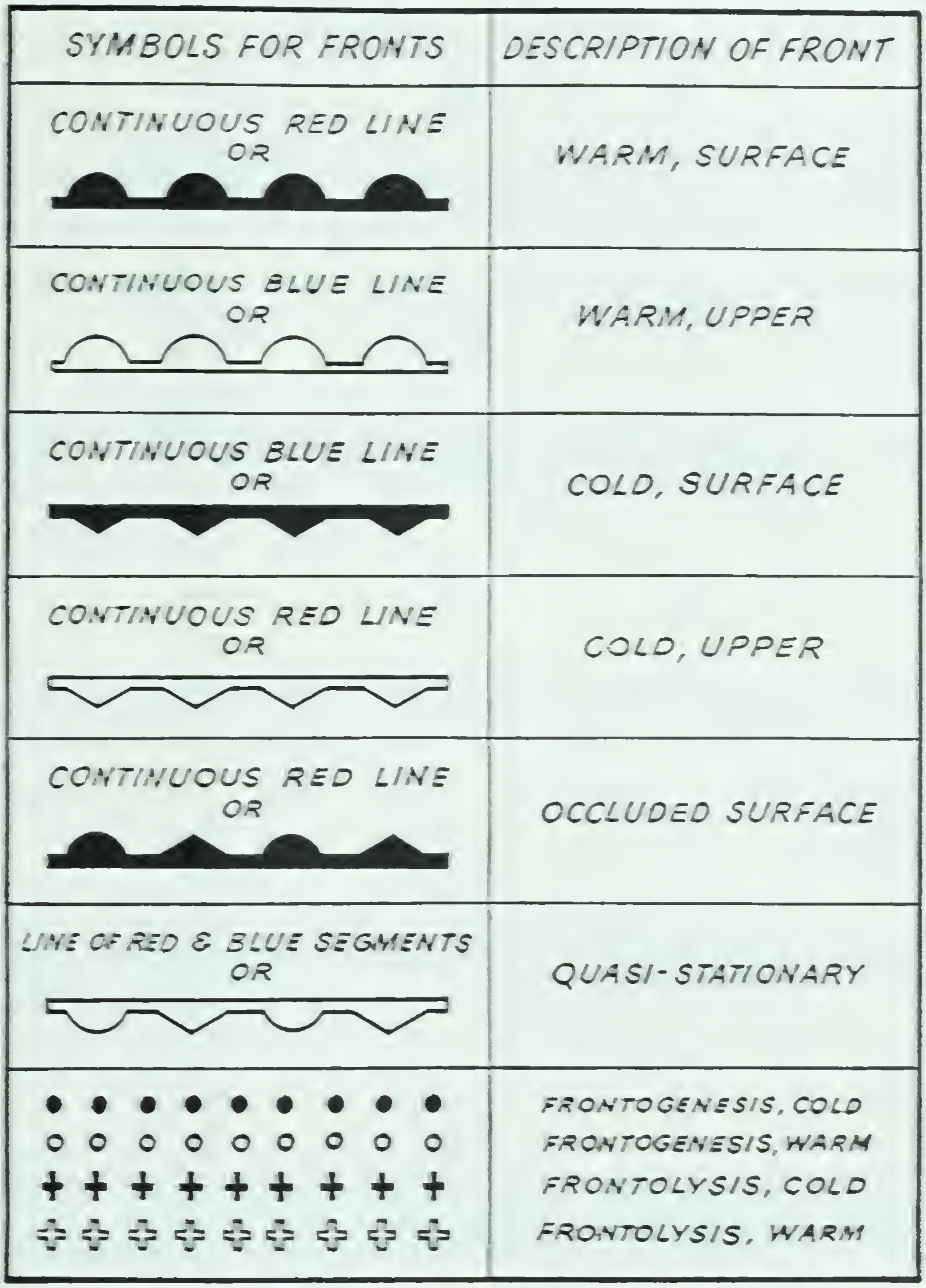
Fig. 71 *a*. Station model

Reading daily weather maps. In order to follow the various types of weather which move over the surface of the earth it is necessary to collect data from a great number of stations and to enter this weather information on maps. When all the observations are taken at the same time the map on which the data are plotted is called a *synoptic weather map*.

In the United States complete observations for use on synoptic maps are made four times a day at 6-hour intervals beginning at 1:30 A.M. E.S.T. The reports are collected at forecast centers by means of radio, teletype, telephone, and telegraph, and are used in preparation of the 6-hour maps. Observations are made also at 1-hour intervals at airway stations. Observations are made also by ships at sea and are sent by radio to land stations.

Weather codes and symbols are used to enter complete data on maps. Thus space is conserved.

The data are placed around the station circle, as shown in Figure 71 *a*. If the station report is missing, the fact is indicated by placing the letter "M" in the station circle. An explanation of weather symbols follows.



SYMBOLS FOR FRONTS	DESCRIPTION OF FRONT
CONTINUOUS RED LINE OR	WARM, SURFACE
CONTINUOUS BLUE LINE OR	WARM, UPPER
CONTINUOUS BLUE LINE OR	COLD, SURFACE
CONTINUOUS RED LINE OR	COLD, UPPER
CONTINUOUS RED LINE OR	OCCLUDED SURFACE
LINE OF RED & BLUE SEGMENTS OR	QUASI-STATIONARY
● ● ● ● ● ● ● ● ●	FRONTOGENESIS, COLD
○ ○ ○ ○ ○ ○ ○ ○ ○	FRONTOGENESIS, WARM
✚ ✚ ✚ ✚ ✚ ✚ ✚ ✚ ✚	FRONTOLYSIS, COLD
✙ ✙ ✙ ✙ ✙ ✙ ✙ ✙ ✙	FRONTOLYSIS, WARM

Fig. 71 *b*. Identification and description of fronts

Lines. The heavy red and blue lines on the accompanying weather maps are called *fronts*. They separate the air masses of different characteristics. Sometimes fronts are shown as heavy black lines.

The light continuous black lines on the weather map are the

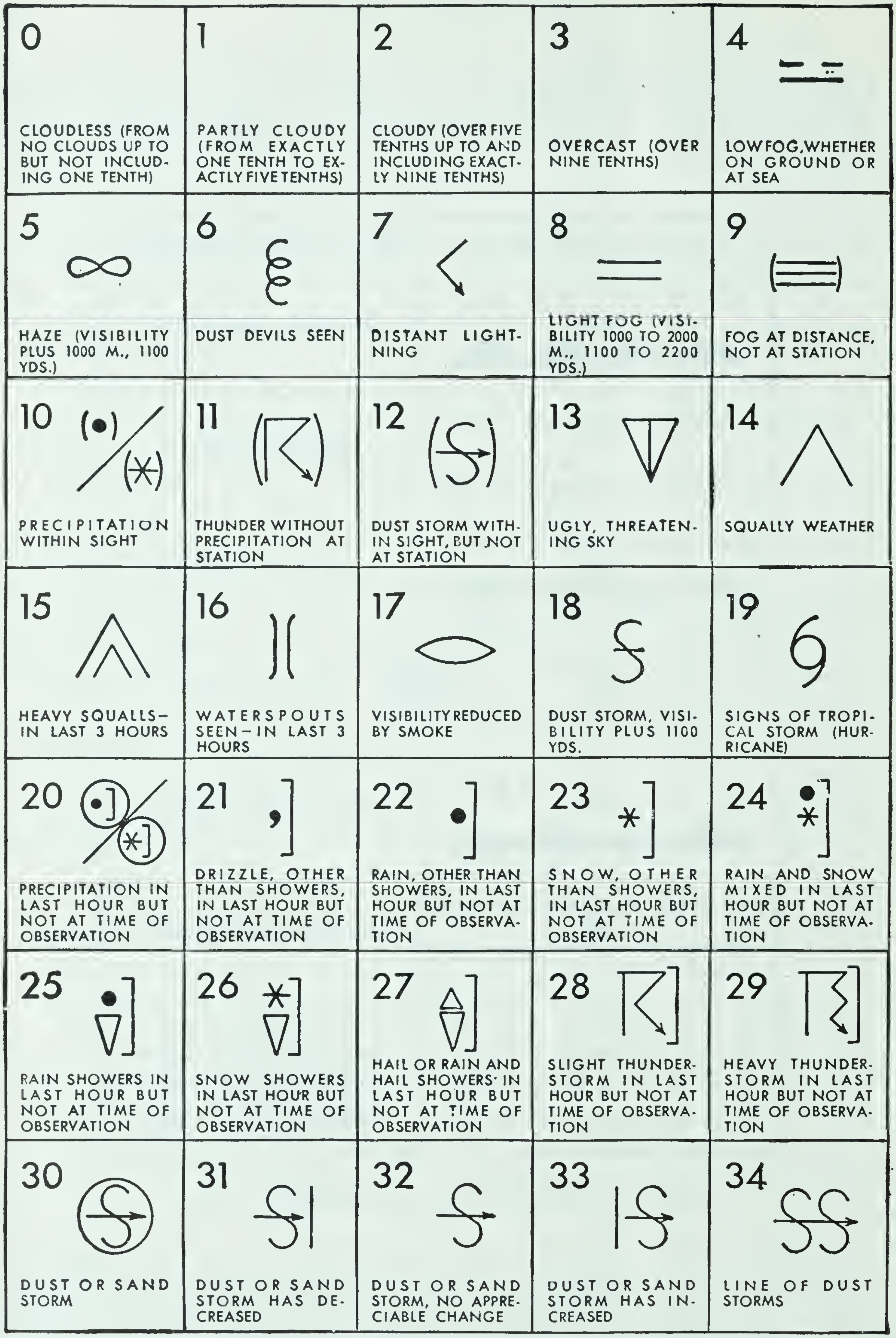

0 CLOUDLESS (FROM NO CLOUDS UP TO BUT NOT INCLUDING ONE TENTH)
1 PARTLY CLOUDY (FROM EXACTLY ONE TENTH TO EXACTLY FIVE TENTHS)
2 CLOUDY (OVER FIVE TENTHS UP TO AND INCLUDING EXACTLY NINE TENTHS)
3 OVERCAST (OVER NINE TENTHS)
4 LOW FOG, WHETHER ON GROUND OR AT SEA
5 HAZE (VISIBILITY PLUS 1000 M., 1100 YDS.)
6 DUST DEVILS SEEN
7 DISTANT LIGHTNING
8 LIGHT FOG (VISIBILITY 1000 TO 2000 M., 1100 TO 2200 YDS.)
9 FOG AT DISTANCE, NOT AT STATION
10 PRECIPITATION WITHIN SIGHT
11 THUNDER WITHOUT PRECIPITATION AT STATION
12 DUST STORM WITHIN SIGHT, BUT NOT AT STATION
13 UGLY, THREATENING SKY
14 SQUALLY WEATHER
15 HEAVY SQUALLS—IN LAST 3 HOURS
16 WATERSPOUTS SEEN—IN LAST 3 HOURS
17 VISIBILITY REDUCED BY SMOKE
18 DUST STORM, VISIBILITY PLUS 1100 YDS.
19 SIGNS OF TROPICAL STORM (HURRICANE)
20 PRECIPITATION IN LAST HOUR BUT NOT AT TIME OF OBSERVATION
21 DRIZZLE, OTHER THAN SHOWERS, IN LAST HOUR BUT NOT AT TIME OF OBSERVATION
22 RAIN, OTHER THAN SHOWERS, IN LAST HOUR BUT NOT AT TIME OF OBSERVATION
23 SNOW, OTHER THAN SHOWERS, IN LAST HOUR BUT NOT AT TIME OF OBSERVATION
24 RAIN AND SNOW MIXED IN LAST HOUR BUT NOT AT TIME OF OBSERVATION
25 RAIN SHOWERS IN LAST HOUR BUT NOT AT TIME OF OBSERVATION
26 SNOW SHOWERS IN LAST HOUR BUT NOT AT TIME OF OBSERVATION
27 HAIL OR RAIN AND HAIL SHOWERS IN LAST HOUR BUT NOT AT TIME OF OBSERVATION
28 SLIGHT THUNDERSTORM IN LAST HOUR BUT NOT AT TIME OF OBSERVATION
29 HEAVY THUNDERSTORM IN LAST HOUR BUT NOT AT TIME OF OBSERVATION
30 DUST OR SAND STORM
31 DUST OR SAND STORM HAS DECREASED
32 DUST OR SAND STORM, NO APPRECIABLE CHANGE
33 DUST OR SAND STORM HAS INCREASED
34 LINE OF DUST STORMS

Fig. 72 *a*. Weather symbols

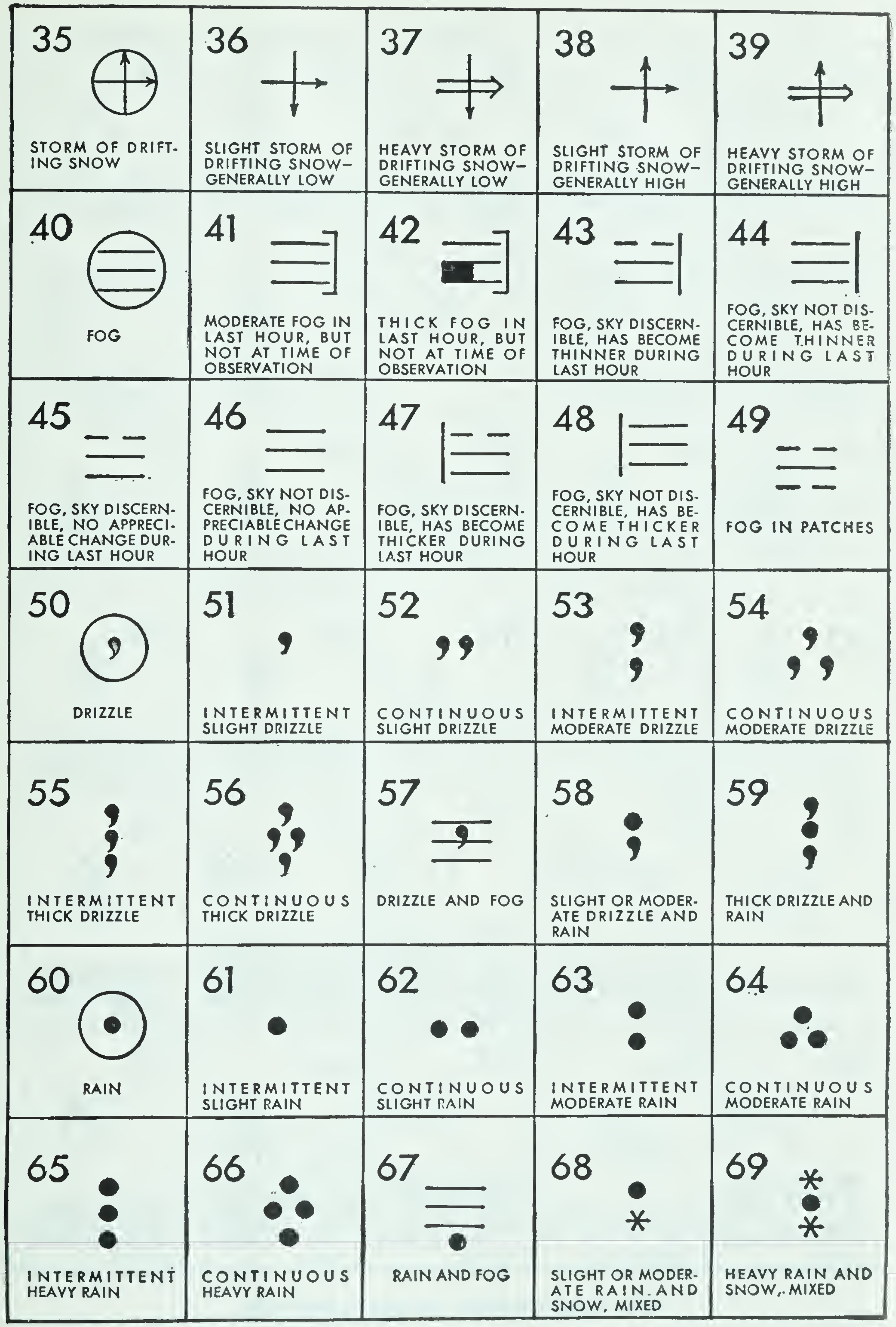

35
STORM OF DRIFTING SNOW
36
SLIGHT STORM OF DRIFTING SNOW—GENERALLY LOW
37
HEAVY STORM OF DRIFTING SNOW—GENERALLY LOW
38
SLIGHT STORM OF DRIFTING SNOW—GENERALLY HIGH
39
HEAVY STORM OF DRIFTING SNOW—GENERALLY HIGH
40
FOG
41
MODERATE FOG IN LAST HOUR, BUT NOT AT TIME OF OBSERVATION
42
THICK FOG IN LAST HOUR, BUT NOT AT TIME OF OBSERVATION
43
FOG, SKY DISCERNIBLE, HAS BECOME THINNER DURING LAST HOUR
44
FOG, SKY NOT DISCERNIBLE, HAS BECOME THINNER DURING LAST HOUR
45
FOG, SKY DISCERNIBLE, NO APPRECIABLE CHANGE DURING LAST HOUR
46
FOG, SKY NOT DISCERNIBLE, NO APPRECIABLE CHANGE DURING LAST HOUR
47
FOG, SKY DISCERNIBLE, HAS BECOME THICKER DURING LAST HOUR
48
FOG, SKY NOT DISCERNIBLE, HAS BECOME THICKER DURING LAST HOUR
49
FOG IN PATCHES
50
DRIZZLE
51
INTERMITTENT SLIGHT DRIZZLE
52
CONTINUOUS SLIGHT DRIZZLE
53
INTERMITTENT MODERATE DRIZZLE
54
CONTINUOUS MODERATE DRIZZLE
55
INTERMITTENT THICK DRIZZLE
56
CONTINUOUS THICK DRIZZLE
57
DRIZZLE AND FOG
58
SLIGHT OR MODERATE DRIZZLE AND RAIN
59
THICK DRIZZLE AND RAIN
60
RAIN
61
INTERMITTENT SLIGHT RAIN
62
CONTINUOUS SLIGHT RAIN
63
INTERMITTENT MODERATE RAIN
64
CONTINUOUS MODERATE RAIN
65
INTERMITTENT HEAVY RAIN
66
CONTINUOUS HEAVY RAIN
67
RAIN AND FOG
68
SLIGHT OR MODERATE RAIN AND SNOW, MIXED
69
HEAVY RAIN AND SNOW, MIXED

Fig. 72 *b*. Weather symbols (continued)

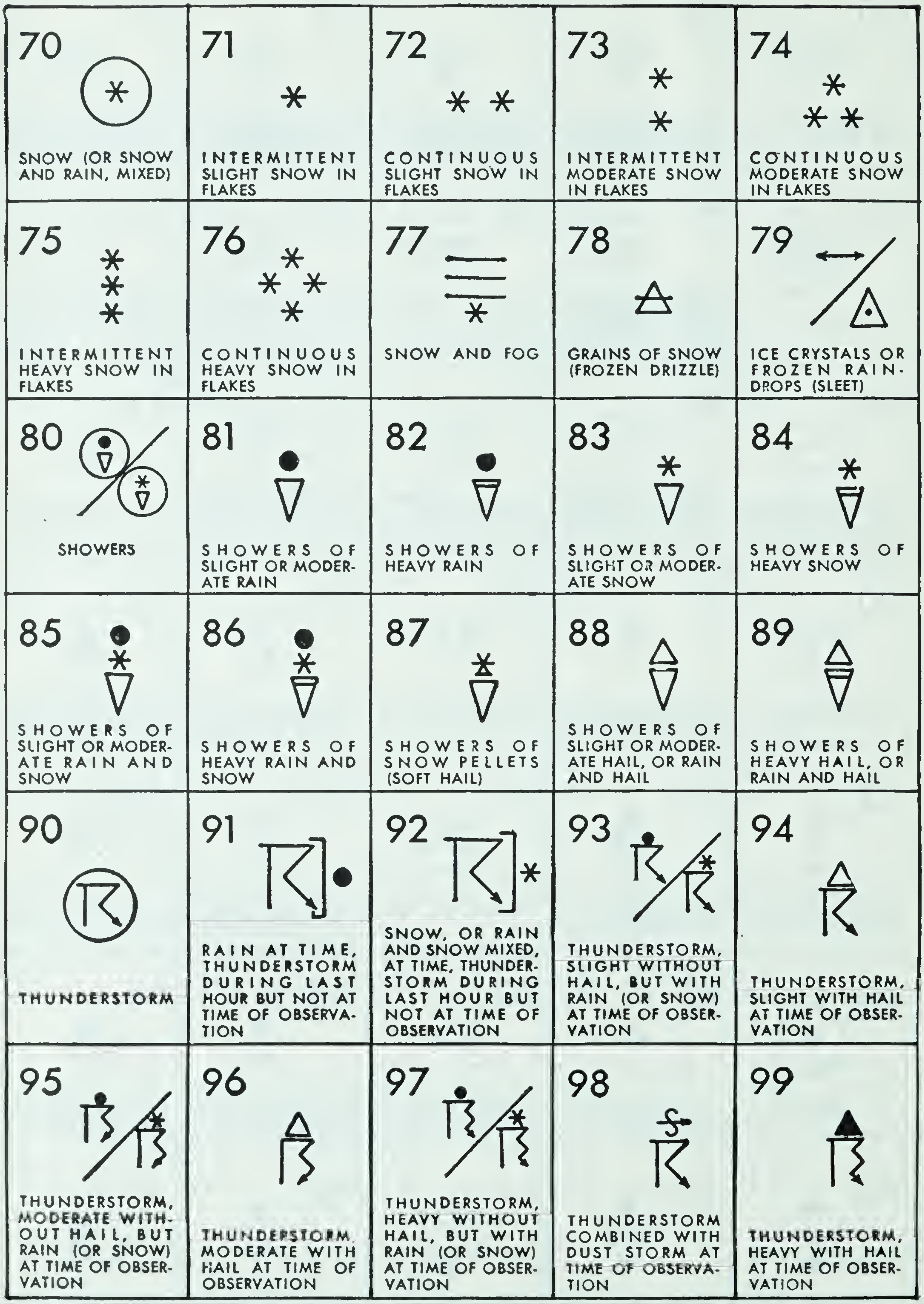
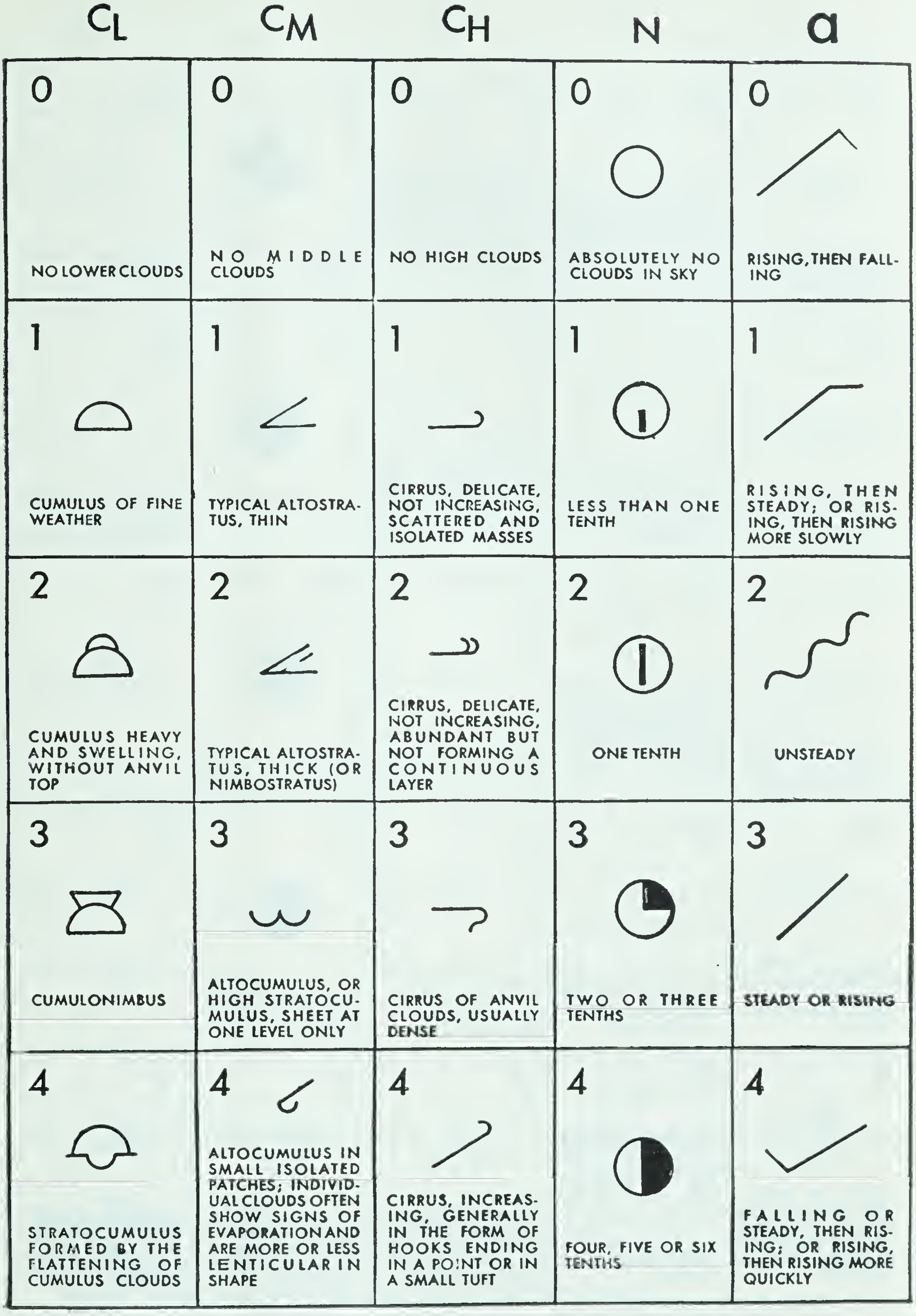

70 SNOW (OR SNOW AND RAIN, MIXED)
71 INTERMITTENT SLIGHT SNOW IN FLAKES
72 CONTINUOUS SLIGHT SNOW IN FLAKES
73 INTERMITTENT MODERATE SNOW IN FLAKES
74 CONTINUOUS MODERATE SNOW IN FLAKES
75 INTERMITTENT HEAVY SNOW IN FLAKES
76 CONTINUOUS HEAVY SNOW IN FLAKES
77 SNOW AND FOG
78 GRAINS OF SNOW (FROZEN DRIZZLE)
79 ICE CRYSTALS OR FROZEN RAINDROPS (SLEET)
80 SHOWERS
81 SHOWERS OF SLIGHT OR MODERATE RAIN
82 SHOWERS OF HEAVY RAIN
83 SHOWERS OF SLIGHT OR MODERATE SNOW
84 SHOWERS OF HEAVY SNOW
85 SHOWERS OF SLIGHT OR MODERATE RAIN AND SNOW
86 SHOWERS OF HEAVY RAIN AND SNOW
87 SHOWERS OF SNOW PELLETS (SOFT HAIL)
88 SHOWERS OF SLIGHT OR MODERATE HAIL, OR RAIN AND HAIL
89 SHOWERS OF HEAVY HAIL, OR RAIN AND HAIL
90 THUNDERSTORM
91 RAIN AT TIME, THUNDERSTORM DURING LAST HOUR BUT NOT AT TIME OF OBSERVATION
92 SNOW, OR RAIN AND SNOW MIXED, AT TIME, THUNDERSTORM DURING LAST HOUR BUT NOT AT TIME OF OBSERVATION
93 THUNDERSTORM, SLIGHT WITHOUT HAIL, BUT WITH RAIN (OR SNOW) AT TIME OF OBSERVATION
94 THUNDERSTORM, SLIGHT WITH HAIL AT TIME OF OBSERVATION
95 THUNDERSTORM, MODERATE WITHOUT HAIL, BUT RAIN (OR SNOW) AT TIME OF OBSERVATION
96 THUNDERSTORM, MODERATE WITH HAIL AT TIME OF OBSERVATION
97 THUNDERSTORM, HEAVY WITHOUT HAIL, BUT WITH RAIN (OR SNOW) AT TIME OF OBSERVATION
98 THUNDERSTORM COMBINED WITH DUST STORM AT TIME OF OBSERVATION
99 THUNDERSTORM, HEAVY WITH HAIL AT TIME OF OBSERVATION

Fig. 72 *c*. Weather symbols (continued)



C_L	C_M	C_H	N	a
0 NO LOWER CLOUDS	0 NO MIDDLE CLOUDS	0 NO HIGH CLOUDS	0 ABSOLUTELY NO CLOUDS IN SKY	0 RISING, THEN FALLING
1 CUMULUS OF FINE WEATHER	1 TYPICAL ALTOSTRATUS, THIN	1 CIRRUS, DELICATE, NOT INCREASING, SCATTERED AND ISOLATED MASSES	1 LESS THAN ONE TENTH	1 RISING, THEN STEADY; OR RISING, THEN RISING MORE SLOWLY
2 CUMULUS HEAVY AND SWELLING, WITHOUT ANVIL TOP	2 TYPICAL ALTOSTRATUS, THICK (OR NIMBOSTRATUS)	2 CIRRUS, DELICATE, NOT INCREASING, ABUNDANT BUT NOT FORMING A CONTINUOUS LAYER	2 ONE TENTH	2 UNSTEADY
3 CUMULONIMBUS	3 ALTOCUMULUS, OR HIGH STRATOCUMULUS, SHEET AT ONE LEVEL ONLY	3 CIRRUS OF ANVIL CLOUDS, USUALLY DENSE	3 TWO OR THREE TENTHS	3 STEADY OR RISING
4 STRATOCUMULUS FORMED BY THE FLATTENING OF CUMULUS CLOUDS	4 ALTOCUMULUS IN SMALL ISOLATED PATCHES; INDIVIDUAL CLOUDS OFTEN SHOW SIGNS OF EVAPORATION AND ARE MORE OR LESS LENTICULAR IN SHAPE	4 CIRRUS, INCREASING, GENERALLY IN THE FORM OF HOOKS ENDING IN A POINT OR IN A SMALL TUFT	4 FOUR, FIVE OR SIX TENTHS	4 FALLING OR STEADY, THEN RISING; OR RISING, THEN RISING MORE QUICKLY

Fig. 72 *d*. Table of weather map symbols

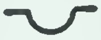
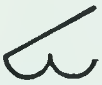
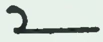
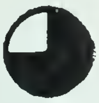
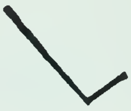
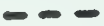
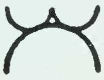
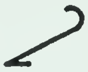
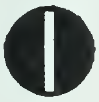
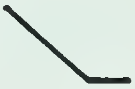
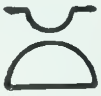
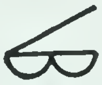
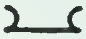
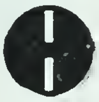
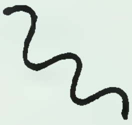
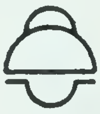
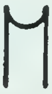
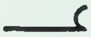
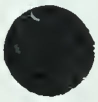
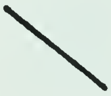
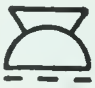
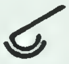
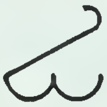
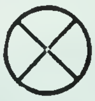
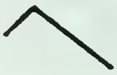
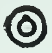
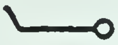
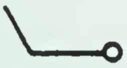
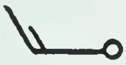
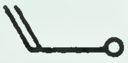
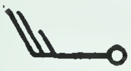
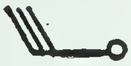
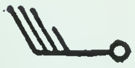
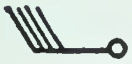
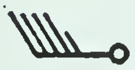
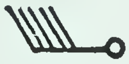
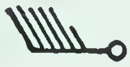
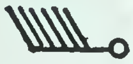
C_L	C_M	C_H	N	a
5  LAYER OF STRATUS OR STRATOCUMULUS	5  ALTOCUMULUS ARRANGED IN MORE OR LESS PARALLEL BANDS OR AN ORDERED LAYER ADVANCING OVER THE SKY	5  CIRRUS (OFTEN IN POLAR BANDS) OR CIRROSTRATUS ADVANCING OVER THE SKY BUT NOT MORE THAN 45° ABOVE THE HORIZON	5  SEVEN OR EIGHT TENTHS	5  FALLING, THEN RISING
6  LOW BROKEN UP CLOUDS OF BAD WEATHER	6  ALTOCUMULUS FORMED BY A SPREADING OUT OF THE TOPS OF CUMULUS	6  CIRRUS (OFTEN IN POLAR BANDS) OR CIRROSTRATUS ADVANCING OVER THE SKY AND MORE THAN 45° ABOVE THE HORIZON	6  NINE TENTHS	6  FALLING, THEN STEADY; OR FALLING, THEN FALLING MORE SLOWLY
7  CUMULUS OF FINE WEATHER AND STRATOCUMULUS	7  ALTOCUMULUS ASSOCIATED WITH ALTOSTRATUS OR ALTOSTRATUS WITH A PARTIALLY ALTOCUMULUS CHARACTER	7  VEIL OF CIRROSTRATUS COVERING THE WHOLE SKY	7  MORE THAN NINE TENTHS BUT WITH OPENINGS	7  UNSTEADY
8  HEAVY OR SWELLING CUMULUS, OR CUMULONIMBUS, AND STRATOCUMULUS	8  ALTOCUMULUS CASTELLATUS, OR SCATTERED CUMULIFORM TUFTS	8  CIRROSTRATUS NOT INCREASING AND NOT COVERING THE WHOLE SKY	8  SKY COMPLETELY COVERED WITH CLOUDS	8  FALLING
9  HEAVY OR SWELLING CUMULUS (OR CUMULONIMBUS) AND LOW RAGGED CLOUDS OF BAD WEATHER	9  ALTOCUMULUS IN SEVERAL SHEETS AT DIFFERENT LEVELS, GENERALLY ASSOCIATED WITH THICK FIBROUS VEILS OF CLOUD AND A CHAOTIC APPEARANCE OF THE SKY	9  CIRROCUMULUS PREDOMINATING, ASSOCIATED WITH A SMALL QUANTITY OF CIRRUS	9  SKY OBSCURED BY FOG, DUST STORM, OR OTHER PHENOMENON	9  STEADY OR RISING, THEN FALLING; OR FALLING, THEN FALLING MORE QUICKLY

Fig. 72 *e.* Table of weather map symbols (continued)

Beaufort number	Map symbol	Descriptive word[1]	Velocity (miles per hour)	Specifications for estimating velocities
0		Calm	Less than 1	Smoke rises vertically.
1			1 to 3	Direction of wind shown by smoke drift but not by wind vanes.
2		Light	4 to 7	Wind felt on face; leaves rustle; ordinary vane moved by wind.
3		Gentle	8 to 12	Leaves and small twigs in constant motion; wind extends light flag.
4		Moderate	13 to 18	Raises dust and loose paper; small branches are moved.
5		Fresh	19 to 24	Small trees in leaf begin to sway; crested wavelets form on inland water.
6			25 to 31	Large branches in motion; whistling heard in telegraph wires; umbrellas used with difficulty.
7		Strong	32 to 38	Whole trees in motion; inconvenience felt in walking against the wind.
8			39 to 46	Breaks twigs off trees; generally impedes progress.
9		Gale	47 to 54	Slight structural damage occurs (chimney pots & slate removed).
10			55 to 63	Trees uprooted; considerable structural damage occurs.
11		Whole gale	64 to 75	Rarely experienced; accompanied by widespread damage.
12		Hurricane	Above 75	

[1] Except "calm," these terms not to be used in reports of velocity.

Fig. 72 *f*. Beaufort scale and wind velocity symbols isobars and pass through points of equal sea-level pressure. The isobars identify the areas of high and low pressure.

Shading. On regular Government weather maps the geographical area where precipitation is falling at the time of the observation is shown by the use of a green color, or dot shading. The amount of precipitation at each station in the past 18 hours is heavily underlined.

Sources of air masses. The large letters which indicate the air masses are shown on the Government maps in red and blue. The red abbreviations indicate air of a tropical origin; the blue, air of polar origin. On the weather maps used in this book these abbreviations are printed in black. It is possible on such maps to trace the origin and basic characteristics of air masses. For example, the letter P denotes the polar type of relatively dry and cold air from northerly or polar regions. The letter T denotes the tropical type of relatively moist and warm air from southerly and tropical regions. The letters placed before the letters T and P show that the air mass is classified as maritime m or continental c. The letters placed after T and P show that the air mass is colder k or warmer w than the surface over which the air is moving. Mixtures of air masses are denoted by plus signs, +, and transitional changes of air masses from one type to another are indicated by arrows, →. One air mass superimposed upon another is indicated by placing a line, ▭, between the two labels.

$P =$ Polar; $c =$ Continental; $T =$ Tropical; $m =$ Maritime; $S =$ Superior (very dry); $k =$ colder; $w =$ Warmer.

The first of the series of maps, A-1, represents weather conditions over the country, as observed at 7:30 P.M. E.S.T., for April 17, 1940. Areas of high pressure are located along the Pacific Coast, between the Cascade and Sierra Nevada mountains and the Rocky Mountains, over the Central High Plains; in southeastern Canada, about the St. Lawrence Valley, and along the Florida Peninsula.

Areas of low pressure appear in the northwestern corner of the United States, the southwest corner of the United States, the southern tip of Texas, and the vast territory between the Missouri River and the Appalachian Mountains. The major storm center is the last area mentioned. This area is accompanied by precipitation, which is evidenced by the appropriate symbols.

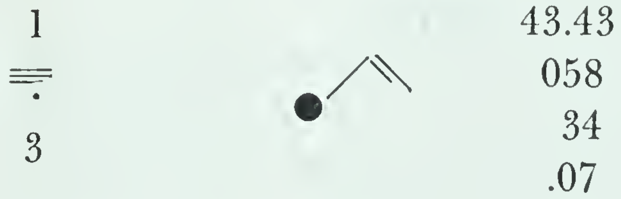
A survey of the wind symbols on the map shows that there is a general movement of the winds from areas of high pressure into areas of low pressure. The wind in high-pressure areas moves in a clockwise direction. In contrast, the winds in the low-pressure areas blow in a counterclockwise direction.

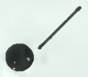
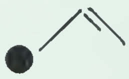
Winds moving in from the Gulf of Mexico, according to the symbols, are heavily laden with moisture. Winds that originate over the land contain very little moisture.

The heavy black line with symbolic designations (see index of symbols on charts) is the boundary between two air masses with different characteristics. The colder polar air has formed a wedge under the warmer tropical air and thus established a cold front. The warmer tropical air is moving up over the colder polar air, thus establishing a warm front. Where the line shows alternate symbols the two air masses have ceased to move, and thus a stationary front is established. The dotted line represents a very complicated weather phenomenon.

WEATHER CONDITIONS AT DETROIT, MICHIGAN
7:30 P.M. E.S.T., Wednesday, April 17, 1940.

Detroit—Station Model



WEATHER OBSERVATION	SYMBOL	INTERPRETATION
Temperature	43	43° Fahrenheit
Dew-point temperature	43	43° Fahrenheit
Pressure	058	1,005.8 millibars
Pressure tendency	34	Steady or rising, then falling 34 millibars in the past 3 hours
Precipitation since 12:30 P.M.	.07	.07 inches
Wind direction		Blowing west by south
Wind velocity		8 to 12 miles per hour
Sky cover	●	Overcast
Clouds	Not given	Probably strato-cumulus
Ceiling	3	300 feet to base of clouds
Weather	$\underset{\cdot}{\equiv}$	Continued rain and fog
Visibility	1	One mile

It is sufficient to state here that this front, which is known as *frontogenesis,* will probably become, within a short period, a warm-surface front.

Where the cold-air mass and the warm-air mass meet in the area between the Missouri River and the Appalachian Mountains a cyclone is in its second stage of development. Notice how the cold polar air which is moving faster than the warm tropical air is bending the front in a counterclockwise direction. Within 24 hours the two fronts will probably be brought together and thus eliminate the warm sector of air. In this way the cyclone will destroy itself. Weather conditions at Detroit as shown on the map are presented as a "station model," and the symbols are explained in the chart given on page 133.

Exercise 57. Prepare a similar station model and interpretation chart for Cheyenne, Wyoming; Salt Lake City, Utah; and Nashville, Tennessee.

Exercise 58. How do weather conditions at the three cities differ from those recorded at Detroit?

Flying conditions in the northern portion of this cyclonic storm area are poor because of the overcast condition of the sky, accompanied by rains and fogs. The chart on page above shows how the data are collected at Detroit, Michigan, and appears on the weather map for April 17, 1940. To interpret the weather conditions at Detroit it will be necessary to refer to the Station Model (Fig. 71) and the accompanying weather symbols. The chart below the station model of Detroit (see chart on page 133) is a brief description of the conditions at that point.

The second of the series of maps, B-1, represents weather conditions over the United States as observed at 1:30 A.M. E.S.T., for April 18, 1940. The areas of high and low pressure have moved between 200 and 300 miles to the east and northeast. A new high-pressure area is developing along the coast of Washington and Oregon, and a well-developed cold front appears.

The cyclone is in its third stage of development. The winds moving in a counterclockwise direction are bending the cold front and bringing it closer to the stationary warm front. The warm sector of tropical marine air is being squeezed out of this area. The moisture area has increased in area and has moved to the north and east.

Suppose an aviator wishes to fly from Detroit to Omaha. The accompanying chart records weather conditions at Detroit, Chicago, Moline, and Omaha. A careful study of the chart will picture for the aviator weather conditions which he will encounter on his flight.

WEATHER CONDITIONS AT DETROIT, CHICAGO, MOLINE, AND OMAHA, APRIL 17, 1940, 7:30 P.M. E.S.T.

DATE: 4–17–1940 TIME: 7:30 P.M. E.S.T.

CITIES	WEATHER ALONG FLIGHT COURSE			
	Detroit	*Chicago*	*Moline*	*Omaha*
Temperature	43	38	34	46
Dew point	43	26	34	32
Pressure	1005.8	1002.1	1009.8	1015.6
Pressure tendency	34 up, then down	18 unsteady fall	28 down, then up	18 down
Precipitation since 1:30 P.M.	.07 inches	Not indicated	.80 inches	.01 inches
Wind direction	E by NE	N	E by NE	N
Wind velocity	8-12 m.p.h.	13-18 m.p.h.	13-18 m.p.h.	13-18 m.p.h.
Sky cover	Overcast	Overcast	Overcast	Overcast
Clouds	Not indicated	Not indicated	Not indicated	Strato-cumulus
Ceiling	300 feet	400 feet	Not indicated	5000 feet
Weather	Continued rain and fog	Continuous rain	Continuous rain	Fair
Visibility	1 mile	1 mile	1 mile	7 miles

Laboratory Exercise 59. You are planning a flight from Chicago to Washington, D.C. You will stop at Columbus and Pittsburgh. On a chart similar to the chart given above record the weather data for the four cities. Now answer the following questions:

a. What kind of weather will you encounter during your flight?

b. Will you be able to see the land at all times?

c. Will you need to fly blind (with instruments) at any time during the trip? If so, where?

d. Where are you apt to encounter local thunder showers?

The third of the series of maps, C-1, represents weather conditions over the United States as observed at 7:30 A.M. E.S.T. for April 18, 1940. The cyclone has reached its third stage of development. The sector of warm air has greatly diminished. The wind moving in a counterclockwise direction has completely removed the warm portions of the cold front to establish a well-defined cold front. The storm continues to move to the northeast.

A mass of tropical maritime air is pushing up over the mass of polar continental air which has had, up to this time, a cold front. This rising warm air is expanding; hence cooling and condensation are taking place. The new area of precipitation, which includes Memphis and Jackson, is shown in green.

The frontogenesis front, which on previous maps was shown by a series of dots, has now become a warm front.

Laboratory Exercise 60.

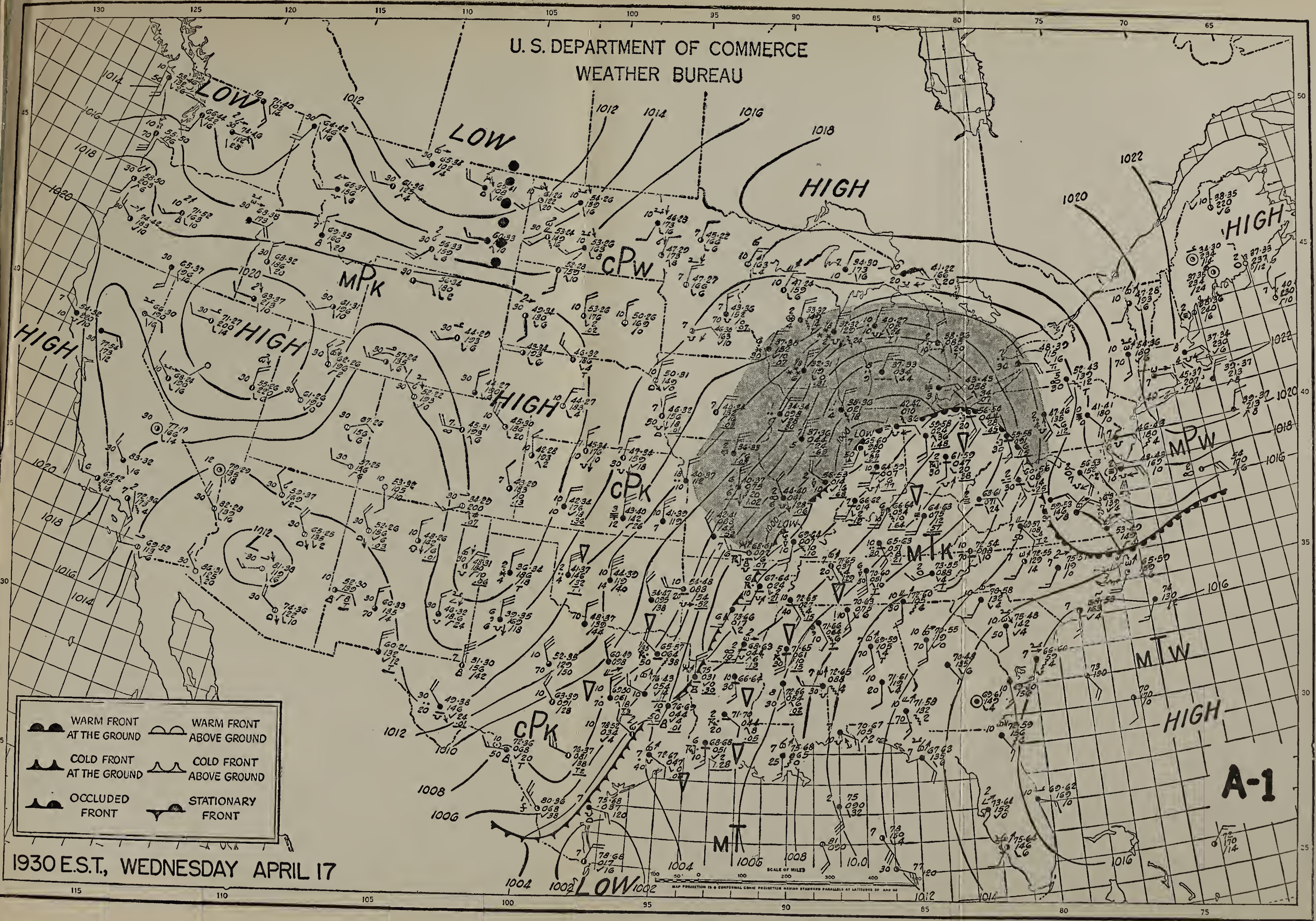
a. Describe weather conditions in Utah.
b. Describe weather conditions in Michigan.
c. Describe weather conditions in South Carolina.
d. Describe weather conditions in Tennessee.

The fourth of the series of maps, D-1, represents weather conditions over the United States as observed at 1:30 P.M. E.S.T. for April 18,1940. Perhaps the most interesting weather phenomenon shown on this map is the cyclone in its fourth and last stage of development. The counterclockwise-moving winds have now completed the circle. As a result an entirely new front has formed at the zone where the cold front has "overtaken" the warm front. This new front is called an *occluded front.* The original wedge of cold air has succeeded in lifting all of the warm surface air into the upper atmosphere.

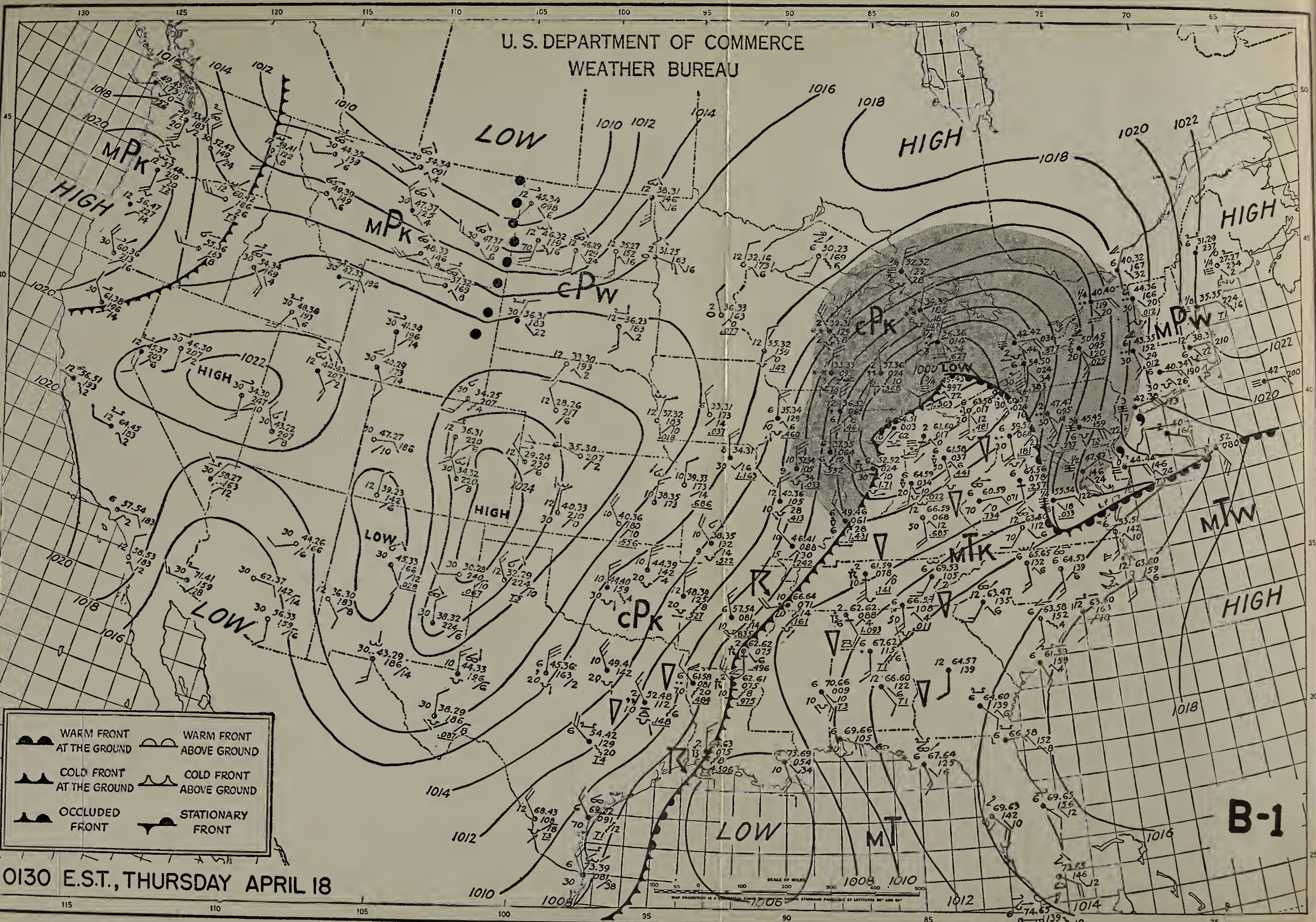
The cyclonic storm has almost completely exhausted itself and the accompanying precipitation is diminishing. Within a few hours New England will probably experience clear weather.

South of the major storm area a cyclone is in the early stages of development. This is a small storm and may or may not completely develop.

In order to show the weather changes which take place within a period of 24 hours at a definite place a chart is presented here. This chart presents weather at Buffalo, throughout a 24-hour period. The chart is self-explanatory (page 137).



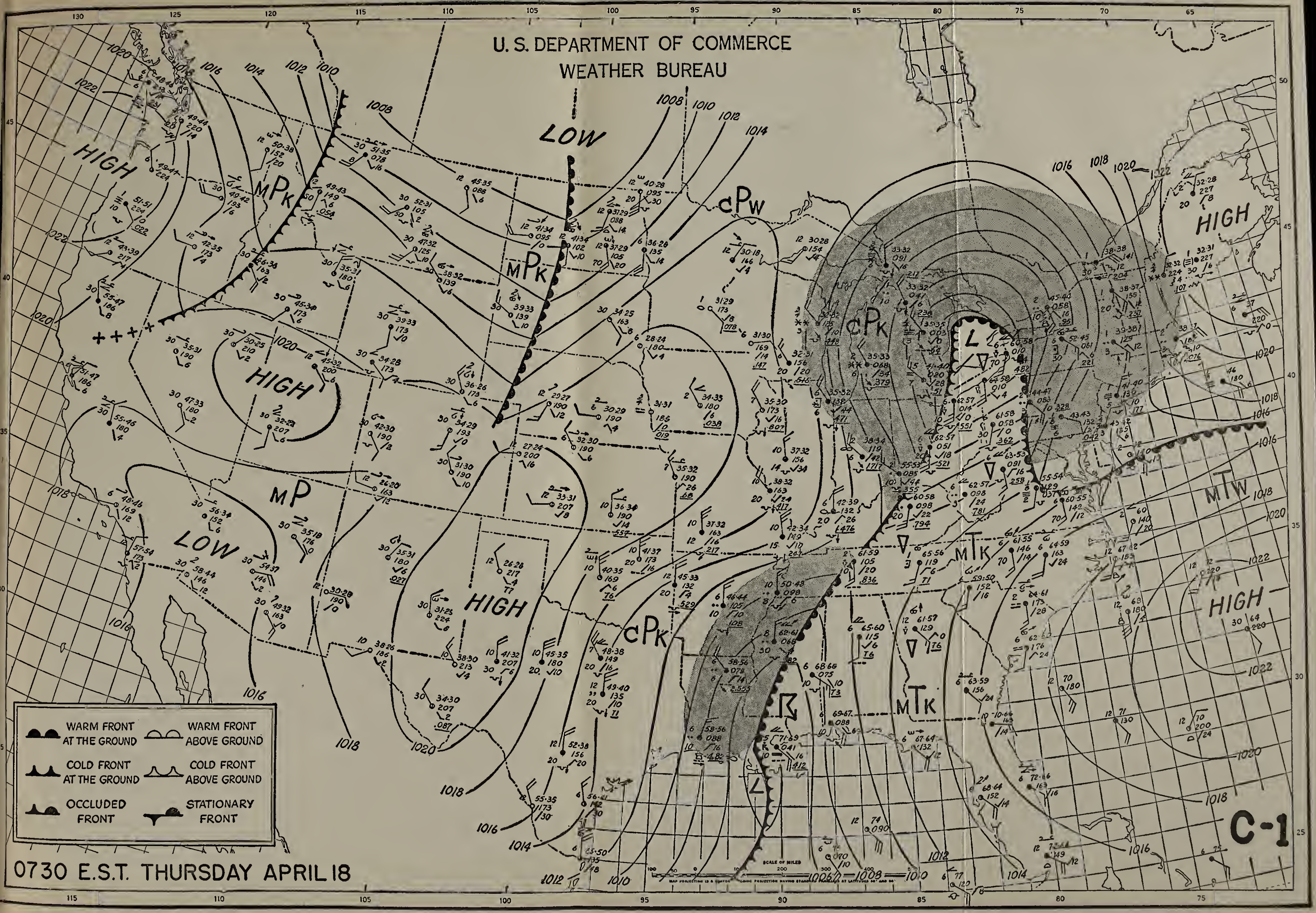
1930 E.S.T., WEDNESDAY APRIL 17



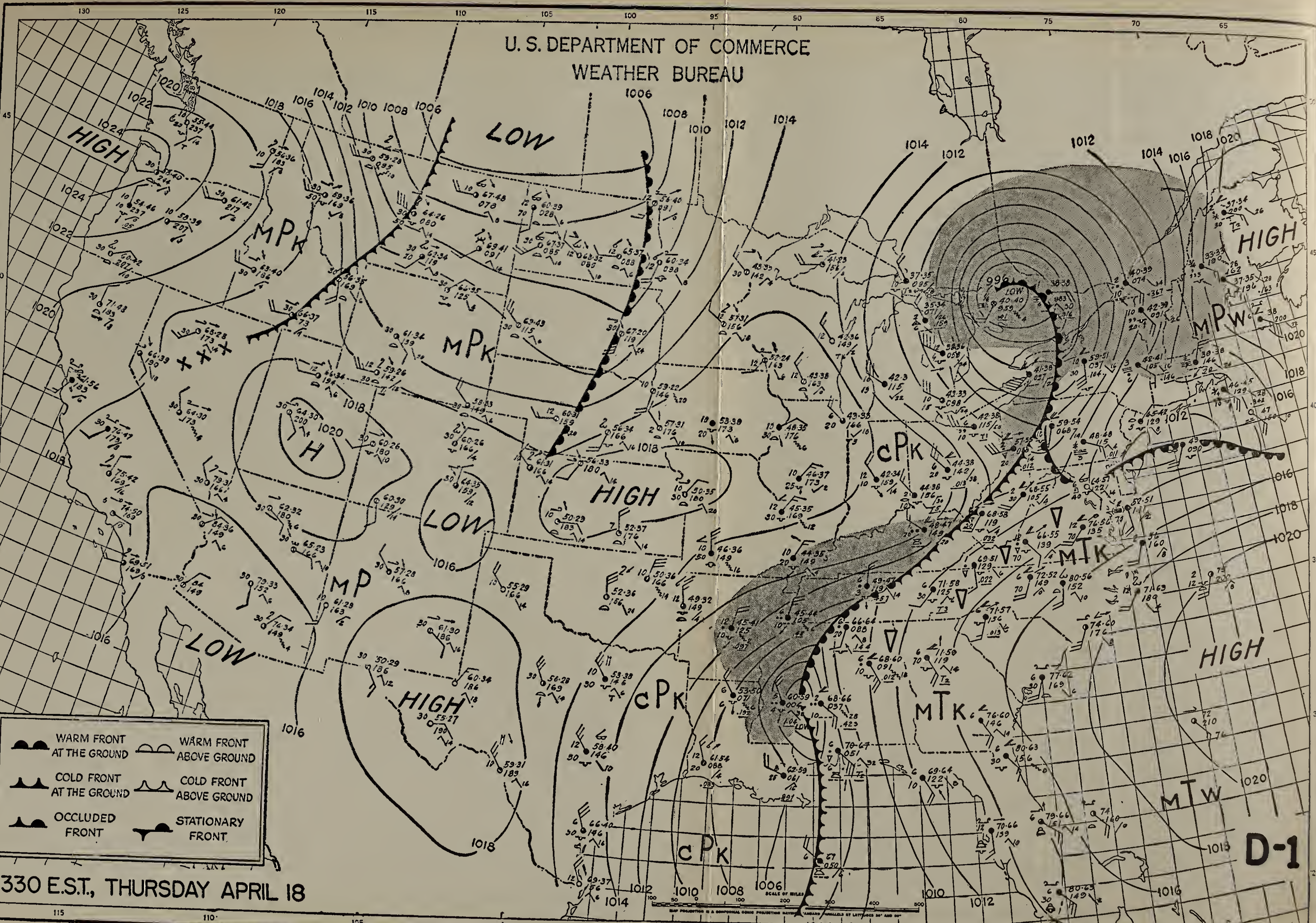
U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU

0130 E.S.T., THURSDAY APRIL 18

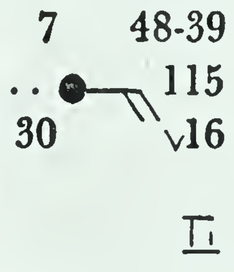
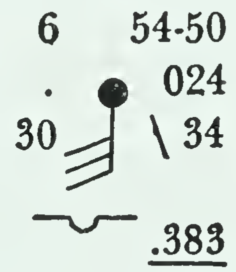
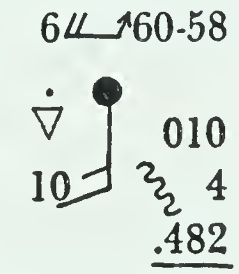
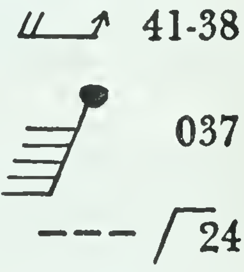
B-1



0730 E.S.T. THURSDAY APRIL 18


U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
1330 E.S.T., THURSDAY APRIL 18
D-1
WARM FRONT AT THE GROUND
WARM FRONT ABOVE GROUND
COLD FRONT AT THE GROUND
COLD FRONT ABOVE GROUND
OCCLUDED FRONT
STATIONARY FRONT
HIGH
LOW
H
mPk
mP
cPk
mTk
mTw
mPw
996
1006
1008
1010
1012
1014
1016
1018
1020
1022
1024

CITY: BUFFALO, NEW YORK

DATE	4–17–40	4–18–40	4–18–40	4–18–40
TIME	7:30 P.M. E.S.T.	1:30 A.M. E.S.T.	7:30 A.M. E.S.T.	1:30 P.M. E.S.T.
Temperature	48	54	60	41
Dew point	39	50	58	38
Pressure	1011.5	1002.4	1001.0	1003.7
Pressure tendency	Fall-rise 16	Falling 34	Unsteady 4	Rise—steady 24
Precipitation in past 6 hours	None indicated	.383 inches	.482 inches	None indicated
Wind direction	E	S	S	SW
Wind velocity	13-18 m.p.h.	25-31 m.p.h.	8-12 m.p.h.	55-63 m.p.h.
Sky cover	Overcast	Overcast	Overcast	Overcast
Clouds	Stratus	Strato-cumulus	Alto-stratus (thick)	Low—broken
Ceiling	3000 feet	3000 feet	1000 feet	Above 10,000 feet
Weather	Continue—slight rain	Intermittent—slight rain	Light rain	Clearing
Visibility	7 miles	6 miles	6 miles	Unlimited
Model				

Laboratory Exercise 61.

a. On separate charts similar to those on page 135 record weather data for San Diego, Seattle, Fort Worth, and Boston.

b. What weather conditions have taken place at these four cities during the 24-hour period?

c. What would be the weather hazards to flight, if any, at these four cities?

Exercise 62. How does the aviator make use of the daily weather map?

Exercise 63. What source, other than the daily weather map, furnishes weather information suitable for the pilot?

Application Activities

1. What is the relation between temperature and air pressure?
2. What is the relation between air pressure and winds?
3. Explain how the air masses form cold, warm, occluded, or stationary fronts.
4. What types of weather will the aviator be likely to experience in crossing each of the four fronts?
5. Explain the life cycle of the cyclone.
6. Name and describe weather hazards which confront the aviator.

Bibliography—Unit II

1. Halpine, Charles G., *A Pilot's Meteorology,* Van Nostrand Co., Inc., 1941
2. Jordanoff, Assen, *Safety in Flight,* Funk and Wagnalls, 1939
3. Jordanoff, Assen, *Through the Overcast,* Funk and Wagnalls, 1939
4. Pope, Francis, and Otis, Arthur S., *Elements of Aeronautics,* World Book Company, 1941.
5. Stewart, George R., *Storm,* Random House, 1941.
6. Haynes, B. C., *Meteorology for Pilots,* Civil Aeronautics Bulletin No. 25

UNIT III

WHY DOES AN AIRPLANE FLY?

(*Aerodynamics*)

EXPLORATORY ACTIVITIES

1. How it is possible to make a kite fly when the wind is not blowing? What supports a kite in the air?
2. What is the purpose of the tail on a kite? Do you think the tail on an airplane has the same function? Why?
3. If the hand is extended from a rapidly moving automobile with the palm at right angles to the airstream, what happens? Why? What is the effect if the hand is held palm down? What is the effect if the palm is inclined at a small angle to the airstream?
4. What happens to an automobile if it turns a corner too fast? Why are railroad tracks on a curve banked, or set at an angle to the horizon? How does an airplane make a turn?
5. Cut a strip of paper about two inches wide and a foot long. Hold one end just under the mouth and blow over the top of the strip. What happens? How can you explain this?
6. Make a one-inch fold on each end of a 4″ × 6″ card, so that the folded ends are at right angles to the card and folded in the same direction. Set the card on the legs thus formed and try to blow the card over by blowing under it, through the bridge.

OVERVIEW

The boy or girl who has successfully constructed and flown a kite readily understands that it is possible for the air to support an object which is heavier than air itself. However, initial experiences with kite flying are usually sufficient to convince one that the forces acting on the kite must be carefully and accurately balanced or the kite will not fly. The airplane is, in this respect, very similar to the kite. Once a plane leaves the ground, the forces acting on it are, with the single exception of gravity, all derived from atmospheric pressure. In order for the plane to stay aloft, these forces must at all times bear certain definite relations to each other and to the force of gravitation which is constantly acting to cause the plane to return to the earth.

The pilot of a plane directs its flight through manipulation of the controls, which serve to alter temporarily the relationship of the forces acting on the plane. This in turn regulates the performance of the plane in the air. It is evident, therefore, that the successful pilot must have a thorough understanding not only of the controls themselves but of the ways in which these controls regulate the various forces which together operate to maintain stability of flight. In this unit you will have an opportunity to study these factors. In order to make this study more meaningful, the unit has been organized about the following problems:

1. What physical laws are basic for an understanding of forces acting on an airplane during flight?
2. What are some effects of fluid motion?
3. What forces act on an airplane during flight?
4. What factors determine the lift and drag on an airplane?
5. What factors determine the power required of an airplane engine?
6. How is the stability of a plane maintained?

Problem 1. What physical laws are basic for an understanding of forces acting on an airplane during flight?

Few persons are able to observe the take-off or flight of a modern passenger plane weighing many tons without asking themselves the question, "What holds it up?" A satisfying answer to this question cannot be given in one sentence. Many of the same scientific principles which have made possible older forms of transportation are also involved in the flight of an airplane. If, then, the question is to be satisfactorily answered, it is desirable first to study the more important of these basic principles individually.

Gravitational force. "Everything that goes up must come down," is a common saying that is disputed by none. Each person, from the time he first walks, learns this principle from personal experience. One may argue that if an airplane goes up, it does not come down until the pilot wishes it to. However, at all times during flight, it must be acted upon by a force which resists its return to the earth. The attraction existing between the earth and all bodies on or near it is commonly referred to as *gravity*. In the study of the forces that act to hold up a plane, gravity must of necessity be considered. While in everyday life we are inclined to regard gravity as being the attraction of the earth for objects, actually the force of attraction acts mutually between any two objects in the universe. The scientific name for this mutually attractive force is *gravitation*. Thus, there is a gravitational attraction between the earth and the sun, between the earth and the moon, and between the earth and all stars, planets, and other celestial bodies. One proof that this gravitational force exists is the effect of the moon and sun on the oceans of the earth. The pull between these two bodies and the earth causes tides which in some places rise as high as forty-five feet.

A person may wonder why he does not fall to the moon instead of to the earth. There are two factors that prevent such an occurrence: the mass of the objects and the distance between them. It has been carefully determined that the gravitational force between two bodies is directly proportional to the product of their masses and inversely proportional to the square of the distance between them. This may be written in equation form as:

$$F \propto \frac{M_1 M_2}{r^2}$$

where F is the gravitational force, M_1 and M_2 the two attracting masses, and r the distance between the masses. It is evident from the equation that, as the masses move farther apart, the force of gravitation decreases rapidly. Likewise, any increase in the mass of either body results in an increase in the gravitational force.

Exercise 1. How is the gravitational attraction between two objects affected if the mass of each of the objects is made four times as great?

Exercise 2. Two objects having masses of M_1 and M_2, respectively, are placed in a position such that their centers of mass are 10 feet apart. How is the gravitational force between these objects affected by increasing this distance to 100 feet?

Exercise 3. In problem 2, what changes in the mass of the respective objects when placed 100 feet apart would result in restoring the gravitational force to its value when the bodies were 10 feet apart?

Inertia. Motion of any object—including an airplane—is produced and controlled by the forces acting on the object. A book lying on the table will remain at rest indefinitely unless for some reason the forces acting on it are altered or unless some additional force changes its position or sets it in motion. We are all familiar with the fact that it is difficult to stop suddenly or to change quickly the direction of our movement when running on smooth ice. We easily recall the experience of being thrown violently forward when the driver of an automobile applies the brakes too suddenly. Furthermore, the fact that it requires a greater push to start a stalled automobile rolling along the pavement than it does to keep it rolling once it is started is common knowledge. These are simple everyday examples of a fundamental law of motion first stated by Sir Isaac Newton in 1886 and called the first law of motion. This principle may be summarized as follows:

Objects at rest tend to stay at rest and objects in motion tend to stay in motion in the same straight line and with unchanging speed unless acted upon by an outside force. That property of a body which makes it resist any effort to change its velocity or direction of movement is called *inertia.*

Laboratory Exercise 4. Place a coin on top of a small card and balance card and coin on the fingertip as indicated in Figure 73. Snap the card quickly with the finger of the other hand. Explain results.

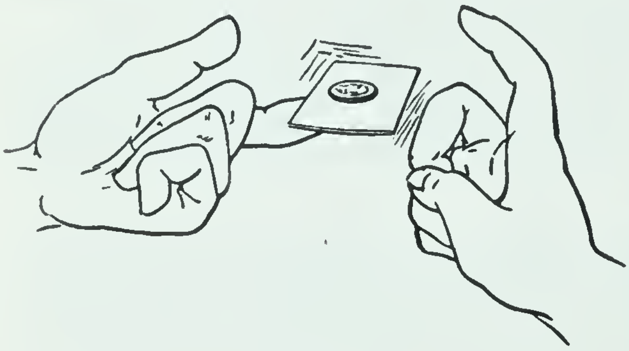


Fig. 73

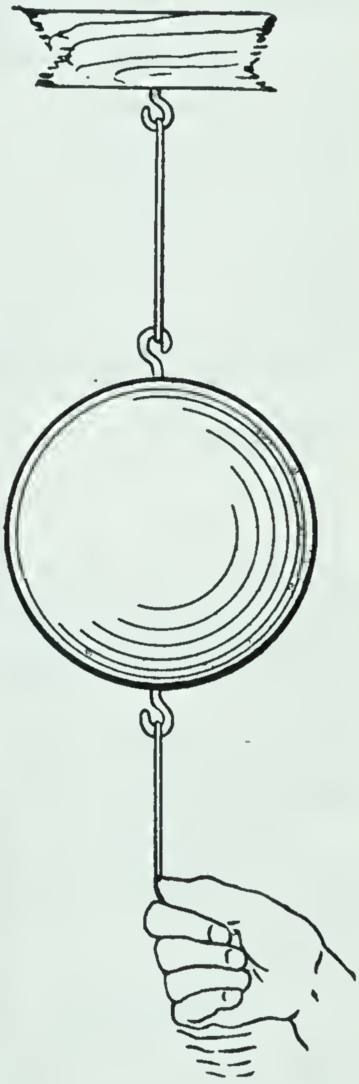


Fig. 74

Laboratory Exercise 5. Suspend a heavy metal ball by means of a light thread just strong enough to support it. Tie a length of the same thread below the ball as shown in Figure 74. Give the lower thread a quick jerk. Give an explanation of what happens.

Linear acceleration. The first law of motion implies that force is necessary (1) to set an object in motion, (2) to change the rate of motion of a moving object, or (3) to change the direction of motion of a moving object. The second law deals with the relation between the acting force and the change in motion produced thereby.

If an automobile traveling at the rate of thirty miles per hour is speeded up to sixty miles per hour, we say that it has been *accelerated.* If this change in the speed of the automobile takes place uniformly and requires ten seconds, the *rate* of change of speed or *acceleration* is three miles per hour each second. A speed of thirty miles per hour is the equivalent of forty-four feet per second and a speed of sixty miles per hour is the same as eighty-eight feet per second. The total change in speed, expressed in feet per second is, therefore, forty-four feet per second, and the acceleration is $\frac{44}{10} =$ 4.4 feet-per-second per second. This is the conventional method of expressing acceleration.

Force is required in order to produce an acceleration. The acceleration imparted to an object by the action of a given force is dependent, not only on the magnitude of the force, but also on the quantity of material which makes up the object. If a force of one pound is applied horizontally to a lead ball lying at rest on a smooth table top, the ball is given an acceleration in the direction of the acting force. If the force acting on the ball is doubled, the acceleration is doubled. On the other hand, if a force of one pound acts similarly on a lead ball of exactly twice the size of the first one, the acceleration produced is exactly one half as great. In this case the second ball, since it contains twice as much material as the first one, is said to have twice its *mass.* It is evident, therefore, that *the acceleration of an object is directly proportional to the force producing the acceleration and inversely proportional to the mass of the object accelerated.* This relation may be expressed algebraically as follows:

$$a \propto \frac{F}{M}.$$

The above relationship between acceleration, force, and mass, which is known as Newton's second law of motion, is the same regardless of whether the acceleration is positive, as in the case of the lead balls, or negative (object losing rather than gaining speed). When suitable units are employed for measuring the quantities a, F, and M, the proportionality sign may be replaced by an equals sign (=) and the equation becomes:

$$a = \frac{F}{M} \tag{1}$$

or

$$F = Ma. \tag{2}$$

The weight of an object is measured by the force with which a mass is pulled toward the center of the earth. If the mass of an object changes (the quantity of material becomes greater or less), there is a corresponding change in its weight. In equation (1), if F represents the force of gravity on an object and M represents the mass of the object, any change in M will produce a corresponding change in F. Thus the value of the ratio $\frac{F}{M}$ remains constant. It follows that the acceleration a due to the force of gravity acting on any mass M should be the same at any given point on the earth's surface. This fact has been amply verified by the experimental determination of the acceleration of freely falling bodies of different masses. It has been found by careful experiments that, neglecting air resistance, freely falling objects at the same point on the earth's surface fall at exactly the same rate regardless of their respective masses. Thus at sea level and at 40° latitude, the acceleration due to gravity has been found to be almost exactly 32.2 feet-per-second per second.

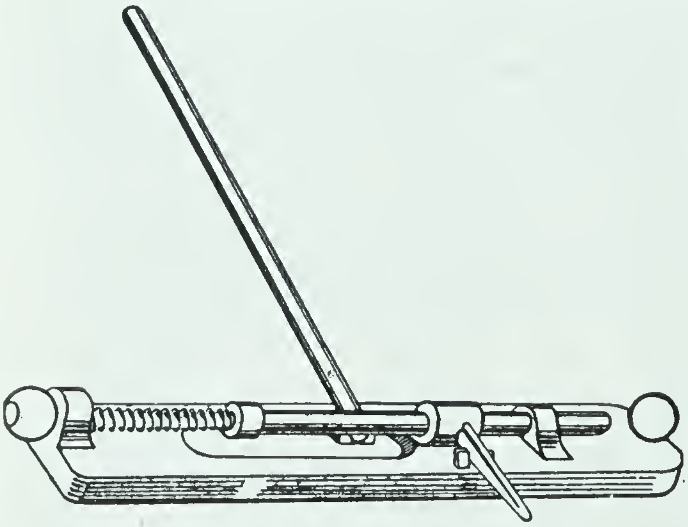


Fig. 75

Laboratory Exercise 6. Use the apparatus shown in Figure 75 to propel one metal ball horizontally and to drop another at the same instant. Note that the balls have different masses since one has a hole in it and the other does not. Do the balls strike the floor at the same time? Explain.

Acceleration due to gravity, usually designated by the letter g, varies slightly with position on the earth's surface because of variation in the earth's radius.

In equation (2) the pull of gravity W may be substituted for F, if at the same time a is replaced by g, the acceleration due to gravity. The equation then becomes:

$$W = Mg \tag{3}$$

or

$$M = \frac{W}{g}. \tag{4}$$

Equation (4) makes it possible to define easily the unit of mass which is used in the study of aerodynamics. If, in this equation, g be replaced by its numerical value, 32.2, M can only be equal to unity when W is also equal to 32.2. The *slug* or unit of mass is therefore defined as *that mass which has a weight numerically equal to the acceleration of gravity.* The mass of an object measured in slugs remains constant for any point on the earth's surface even though its weight may vary slightly from point to point. This is due to the fact that any change in weight is accompanied by a corresponding change in the value of g. Thus in applying the second law of motion ($F = Ma$) to problems in aerodynamics, force is measured in pounds; mass, in slugs; and acceleration in feet-per-second per second.

Centripetal and centrifugal force. The tendency of a moving object to resist any effort to change its direction of motion has already been mentioned. This tendency, called *inertia of motion,* is exemplified by the skidding of an automobile as it turns a corner at high speed or by the tendency of an airplane to skid when the direction of its motion is changed and the angle of bank is inadequate.

A force, called the *centripetal force,* is required to make a body, already in motion, move in a curved or circular path. This force must act on the body and be directed towards the center of rotation.

In Figure 76, the string and ball illustrate centripetal force. The centripetal force exerted upon the ball by the string prevents the ball from moving in a straight line. Equal to and in the opposite direction from the centripetal force is the *centrifugal force.* If the string breaks, both the centrifugal and centripetal forces vanish, and the ball flies off at a tangent to the circle in which it has been rotating. Contrary to the common impression, the ball does not fly off along a radius of the circle, but on a line perpendicular to the radius.

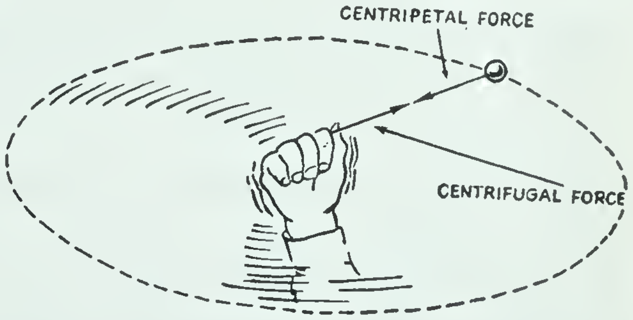


Fig. 76. Centripetal and centrifugal forces

It may easily be shown that the magnitude of either centrifugal or centripetal force varies directly with the mass of the rotating body, and with the square of its linear velocity. On the other hand, if mass and linear velocity are constant, the centrifugal or the centripetal force is decreased with an increase of the radius of rotation. Stated algebraically, the relationship becomes:

$$F = \frac{MV^2}{r}$$

where F is measured in pounds, M in slugs, V in feet per second, and r in feet. This equation represents an application of Newton's second law to motion in a curved path. The relationship is essential in understanding the behavior of an airplane while turning and banking.

Momentum. A 200-pound football player is harder to stop than a player weighing 150 pounds, if each is traveling at the same speed. Likewise, a railroad freight car which is running free may cause great damage to any object that it strikes even though the freight car is moving at a very slow speed. On the other hand, it is well known that a car traveling sixty miles per hour will suffer more damage in striking a stone wall than the same car when traveling only twenty miles per hour. The effect produced by a moving object depends not only on its velocity of motion but also on its mass. The *quantity of motion* of a moving object is measured by the product of its mass and its velocity. This product is commonly designated as the *momentum* of the object.

Conservation of momentum. Anyone who has tried to jump from a rowboat to the shore is familiar with the fact that the boat is pushed backward—acquires a backward velocity—at the same time that the person jumping gives himself a push toward the shore. Again, many boys are familiar with the recoil or kick of a shotgun. The backward movement of the boat is less pronounced if the boat is larger and, therefore, heavier. Likewise the recoil of a gun may be made less objectionable by holding the gun tight against the shoulder. In each of these examples the forward momentum is exactly equal and opposite to the backward momentum. By holding the gun properly, its mass and the mass of the person shooting it act as a unit, and the backward velocity or recoil of the gun is correspondingly lessened.

The examples given are illustrations of the third law of motion, which may be stated in either of two ways:

Whenever one body acquires momentum, some other body acquires an equal and opposite momentum. This is equivalent to saying: **To every action there is an equal and opposite reaction.** As in the case of the other laws of motion, this principle is involved in the understanding of each of the forces acting on an airplane during flight.

Exercise 7. A boy coasting down a hill has an acceleration of four feet per second for each second that he moves. If he starts from rest, what speed will he have at the end of the fifth second?

Exercise 8. A man hits a tennis ball with an impact lasting one-twentieth of a second. The ball rebounds from the racket with a speed of one hundred feet per second. What is the acceleration?

Exercise 9. An airplane starts from rest and takes off at a speed of sixty miles per hour. If the plane was in motion on the ground for only twenty-two seconds, what was its average acceleration in feet-per-second per second?

Exercise 10. If the airplane in problem 9 weighs 3000 pounds, what average force did the propeller exert while taking off?

Exercise 11. Two objects of the same mass rotate in the same circular path; one makes two revolutions while the other makes five revolutions. Compare the centrifugal forces.

Exercise 12. Two objects of different mass rotate with the same speed in the same circular path, but the centrifugal force of one is six times that of the other. Compare the masses.

Exercise 13. An airplane is flying with a constant velocity of one hundred miles per hour. How does the forward pull of the propeller compare with the total effect of all forces acting to retard the forward motion of the plane?

Exercise 14. An airplane weighing 2500 pounds and traveling eighty-five miles per hour is making a turn of 200-foot radius. What is the centrifugal force?

The principle of moments. An understanding of the principle of moments is necessary, particularly in the study of the stability of an airplane. If a rod is balanced horizontally over a knife edge (Fig. 77) and weights are hung from the rod, it is found that in order to balance a weight of ten pounds suspended at a point two feet to the right of the fulcrum, a weight of twenty pounds must be suspended one foot to the left of the fulcrum. The product of a force and the perpendicular distance from the line of action of the force to a point is said to be the *moment* of the force about that point. Thus in Figure 77 the moments of the forces about point F are equal but tend to produce rotation in opposite directions about *F*. In general, moments which tend to produce clockwise rotation about a point are called positive moments; whereas those which induce counterclockwise rotation are negative moments. An object is in rotational equilibrium with respect to an axis when the sum of the clockwise moments about this axis is equal to the sum of the counterclockwise moments about the same axis.

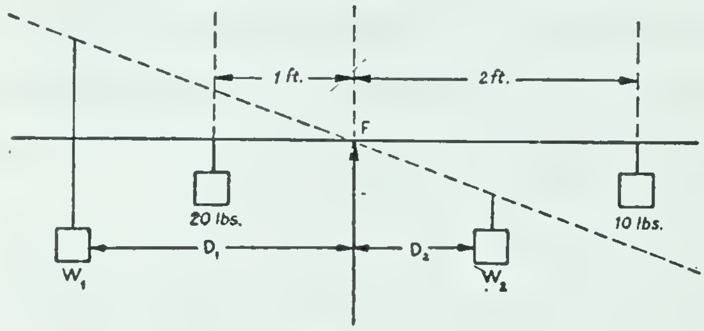


Fig. 77

In dealing with moments it is necessary to pay close attention to the fact that the distance which must be used in calculating a moment is the *perpendicular* distance from the point about which moments are being computed to the line of action of the force. Thus, if the rod in Figure 77 is balanced across the fulcrum in the position indicated by the dotted line, the condition for maintaining this equilibrium when weights W_1 and W_2 are suspended from the rod is that $W_1 \times d_1 = W_2 \times d_2$.

Exercise 15. A weight of fifty pounds is suspended four feet from the point of support of a rigid bar of negligible weight. Where must a force of ten pounds be applied to balance the weight exactly?

Exercise 16. Weights of ten pounds and thirty-five pounds, respectively, are suspended from the ends of a uniform bar six feet long. Where must a support be applied to the bar in order that the entire system may balance? Neglect the weight of the bar.

Relative motion. A man riding on a train which is traveling seventy miles per hour has a speed of seventy miles per hour relative to a fixed point along the track. However, if he walks toward the rear of the train at a speed of four miles per hour, his speed relative to a fixed point on the ground is reduced to sixty-six miles per hour. Conversely, if he walks toward the front of the train at the same speed, his rate of travel with respect to the ground is increased to seventy-four miles per hour. If his train is side-tracked for another traveling in the opposite direction, he may feel, as he sits at a window and watches the other train pass, that he is moving and that the other train is standing still.

To a man riding a motorcycle due east on a perfectly calm day, the wind will appear to be coming from the east with a velocity equal to that of his motorcycle. On the other hand, a south wind will appear to him to be coming from the southeast.

Practically all motion which is studied in aerodynamics is relative motion. The pilot is concerned with the direction of the wind relative to the ground because of its significance in determining weather conditions and its effect during take-off and landing. During flight, however, his plane is continually acted upon by a wind, the apparent direction and velocity of which are partially determined by his direction of flight and his airspeed.

Work. Regardless of how much force is expended, no *work,* in the scientific sense, is done unless motion of the point of application of the force results. Work is measured by the product of force times distance ($W = F \times S$). If force is measured in pounds, and distance in feet, the work accomplished is given in *foot-pounds.* Thus, if a force of four pounds acts on the block of wood as indicated in Figure 78, and as a result of the continuous application of this force the block is moved a distance of two feet along the table top, eight foot-pounds of work have been done.

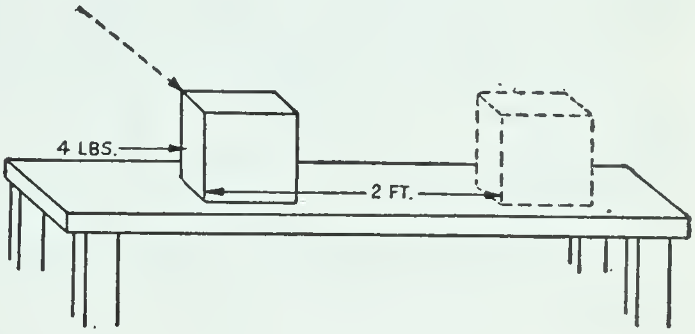


Fig. 78

In applying the work formula care must be taken that the force used in the computation is in line with the resulting motion. For example, if a force is applied to the block in the direction indicated by the dotted arrow, only a part of this force is effective in moving the block across the table. In this case, the remainder of the applied force results in increasing friction between the block and the table top. The technique used in determining the part of the applied force which produces motion of the block, and therefore accomplishes work, will be discussed later.

Power. The actual work accomplished in the illustration of the preceding section is independent of the time required for the force to move the block through the distance indicated. In other words, the time element does not enter into the calculation of work. In everyday life we are frequently more interested in the rate at which a machine works than we are in the total amount of work accomplished. The unit used in aeronautics for the measurement of rate of work or *power* is the *horsepower.* When a machine accomplishes work at the rate of 550 foot-pounds per second or 33,000 foot-pounds per minute, it is said to develop one horsepower.

Energy. Whenever work has been done on a body or substance to place it in its present position or condition, the body is said to possess energy. The capacity for work, or energy, of the body may therefore be measured by the work done in placing it in the position or condition in which it is found. If work has been done in raising an object to a certain height against the force of gravity, the object is said to possess *potential* energy. This potential energy, with reference to the point from which the object was lifted, is equal to the number of foot-pounds of work required to lift it from the point of reference to its position above that point. For example, a weight of 100 pounds suspended 5 feet above the ground is said to have 500 foot-pounds of potential energy with reference to the ground.

An object in motion is said to possess *kinetic energy* equal to the work done in bringing it up to its velocity. If an object at rest is acted upon by a force and, as a result, gains a velocity V, in time t, the acceleration of the body is given by $\frac{V}{t}$. By the second law of motion:

$$F = Ma. \tag{1}$$

If M represents the mass of the body in question and F the force acting to produce the acceleration, then, substituting $\frac{V}{t}$ for a, in equation (1):

$$F = M\frac{V}{t}. \tag{2}$$

The distance traveled by a moving object starting from rest and gaining speed uniformly is equal to average velocity × time. Therefore, if distance traveled by the body be represented by S:

$$S = \frac{0 + V}{2} \times t. \tag{3}$$

Since work is measured by the product of force × distance, the relationships given by formulae (2) and (3) may be used in computing the work done in bringing the object up to its final velocity. Thus:

$$W = F \times S = \frac{MV}{t} \times \frac{Vt}{2} = \tfrac{1}{2}MV^2. \tag{4}$$

It follows that the kinetic energy of a moving object in foot-pounds is given by the formula $\frac{1}{2}MV^2$, when M is in slugs and V is in feet per second.

Exercise 17. A total of 1000 foot-pounds of work was done in moving an object 10 feet across a floor. What was the force necessary to move the object?

Exercise 18. If a boy weighing 130 pounds carries a 50-pound load up a ladder to a height of 50 feet in 15 seconds, how much work does he do? What is his power?

Exercise 19. An engine pulls a train at a speed of 45 miles per hour with a force of 12,250 pounds. How much work does it do in one second? What is its horsepower?

Exercise 20. It required 12 minutes and 15 seconds to pump 200 cubic feet of water into a tank 40 feet high. What horsepower was used? (Note: one cubic foot of water weighs 62.4 pounds.)

Exercise 21. What kinds of energy are possessed by a soaring glider?

Exercise 22. What is the potential energy of a bomb weighing 500 pounds at the instant it is released from a bomber flying at an altitude of 1500 feet (neglect the chemical energy of the bomb)?

Exercise 23. An object weighing one fourth of a pound has a speed of 60 feet per second. What is its K. E. (kinetic energy)?

Exercise 24. An airplane weighing 10 tons has a speed of 240 miles per hour. What is its K. E.?

The composition of forces or velocities. Quantities which involve the idea of direction as well as of magnitude are called *vector quantities* or *vectors.* On the other hand, quantities which involve magnitude only are known as *scalar quantities.* Both velocities and forces are vector quantities; but mass, weight, volume, and density are scalar quantities.

Any vector quantity may be represented graphically by drawing a line in the direction of the line of action of the force or velocity, adjusting its length to scale to represent the magnitude of the quantity, and indicating the direction of action by an arrowhead placed at the end of the line. The resulting arrow is called a vector and represents the vector quantity in both direction and magnitude.

Figure 79 shows two vectors, A and B, representing forces of ten pounds each acting in very nearly the same direction at point P. It is apparent that if the lines of action of A and B coincided exactly, the two forces would have the same effect on point P as a single force of twenty pounds acting in the same direction. This single force, which alone will produce the same effect as two or more other forces acting at the same point, is known as a resultant force. Each of the single forces is called a component force. It is obvious that the resultant of two equal, single forces acting in opposite directions at a point would be zero. It follows that the resultant of an infinite number of vectors having the same line of action and acting at a given point could be calculated by assigning positive and negative values and adding algebraically.

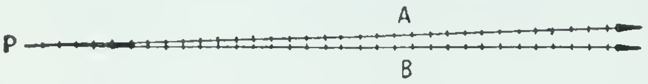


Fig. 79

If two forces act at an angle at a given point *P*, the resultant may be found by graphical means as follows: (1) represent the magnitude and direction of each of the forces by drawing vectors as shown in Figure 80 (*A* and *B*); (2) through the arrow end of each of the vectors *A* and *B*, draw a line parallel to the other vectors (*C* and *D*); (3) draw the diagonal of the parallelogram passing through point *P;* (4) this diagonal *R* represents the resultant of the vectors *A* and *B*. Its magnitude is easily determined by measuring its length and applying the same scale used in the construction of the component vectors *A* and *B*.

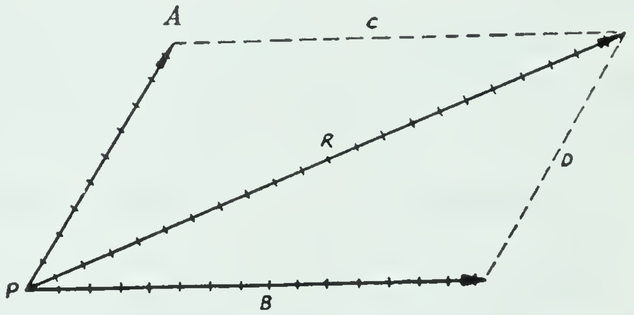


Fig. 80

The process described in the preceding section is called *composition* of forces. By use of this process the resultant of any number of single forces acting at a common point may readily be found. In the case of more than two forces, the resultant of two forces is first found, and this resultant is combined with either another force or with the resultant of another pair of forces, and so on until all components have been included. While the example just discussed has been worked out with forces, velocities or any other vector quantities may be treated similarly.

Students who are familiar with the theorems of trigonometry may solve any problem involving composition of forces directly without the use of graphical procedure. But, considering the matter graphically, a condition frequently occurs in which two component forces are at right angles to each other. In this case the parallelogram of forces is a rectangle, and the square of the hypotenuse is equal to the sum of the squares of the sides of either of the triangles formed by the diagonal.

The resolution of forces or velocities. It is frequently necessary in the study of aerodynamics and elsewhere to be able to separate a known force or velocity into two components acting in known directions. This is accomplished as follows: (1) represent the known force by a vector, *AB* in Figure 81; (2) through both extremities of this vector draw lines in two given directions; (3) extends these lines until they intersect forming a parallelogram (*ACBD* in Fig. 81). The sides of this parallelogram which pass through the point of application of the known force represent the magnitude and direction of the desired component forces. (*AC* and *AD* in Fig. 81.) The exact magnitude may be determined by application of the scale, by use of the right-triangle relationship if a right triangle is involved, or by trigonometric calculation.

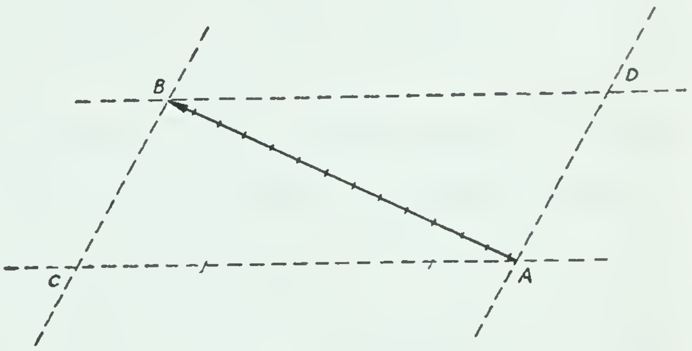


Fig. 81

Exercise 25. Draw vectors representing the following forces, using $\frac{1}{4}$ of an inch to represent a force of one pound.

a. A force of 6 pounds acting horizontally and to the right.

b. A force of 10 pounds acting horizontally and to the left.

c. A force of 7 pounds acting vertically downward.

d. A force of 6 pounds acting diagonally upward.

Exercise 26. A force of 6 pounds acts at an angle of 60° to another force of 10 pounds, both acting simultaneously on the same body. What is the resultant? Solve graphically.

Exercise 27. Two forces act at an angle of 40°. Their resultant is 40 pounds, and one component is a force of 25 pounds. What is the angle which the second component makes with the resultant, and what is the value of the force?

Exercise 28. A force of 60 pounds acts on a body in a direction at right angles to another force of 40 pounds. What single force would keep the body moving?

Exercise 29. A force of 175 pounds acts diagonally downward at an angle of 45° with the horizontal. Find its vertical and horizontal components.

Exercise 30. A car is traveling south at a uniform speed of

60 miles per hour. The wind is blowing from the east at a speed of 25 miles per hour. What is the apparent direction and velocity of the wind as experienced by the driver?

Exercise 31. What is the direction of movement and the approximate velocity of a bomb dropped from an airplane traveling 90 miles per hour, at the end of the second second of its fall? (Neglect air resistance.)

Problem 2. What are some effects of fluid motion?

A fluid is defined as a substance whose particles move easily among themselves and yield more or less readily without disintegrating when a force is applied. In other words, a fluid will flow when a force is impressed upon it. Since both gases and liquids are subject to flow, they are both classed as fluids. The following discussion will consider principally the fluid motion of the air as it affects flight.

Streamlines. A *streamline* may be defined as the path of a moving particle. In a stream of air, the motion or flow of air particles determines the streamlines. Undeflected streamlines are usually represented graphically by a series of parallel lines, although actually each particle may be considered as having its own streamline.

Streamline flow is a smooth, uninterrupted flow past or around an object. Thus, if a flat plate is placed edgewise in a stream of air (Fig. 82), the air flows about the plate in such a manner that the streamlines are only slightly diverted from their straight path and still constitute a relatively smooth flow. If, however, the plate is placed crosswise to the airstream as in Figure 83, the streamlines are diverted. The confused mass of air thus formed produces a positive pressure against the plate that tends to carry it back along the general direction of the flow. This positive pressure is readily detected if the palm of the hand is extended against an airstream formed by the rapid motion of an automobile through the air.

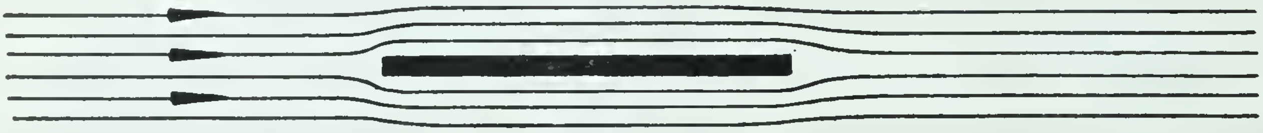


Fig. 82

On the other hand, air that succeeds in getting around the edges of the plate has an increased velocity because of its diversion. This increase in velocity is represented graphically by drawing streamlines closer together. The atmospheric pressure, which is equal in all directions, tends to push the streamlines back into their normal path once the diverting force is removed. However, the increased velocity of the air about the plate creates a reduced pressure, which results in the withdrawal of air from behind the plate. At the same time, there is an additional breakdown of streamlines back of the plate and added turbulence. This relationship between air velocity and lateral pressure will be more completely developed in a later section.

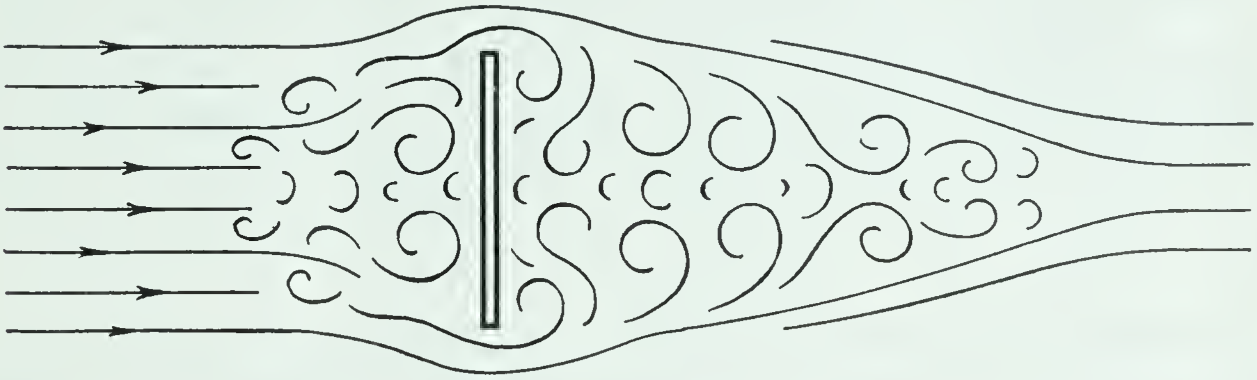


Fig. 83

The turbulence behind the plate (Fig. 83) results in reduced air pressure. This force constitutes a part of the *drag* or backward pull that must be overcome by an airplane in flight. This effect is noticeable behind the older type of transport truck which has a flat, vertical rear. The region of lower pressure formed behind the truck as it moves rapidly is sufficient to cause paper and dirt to swirl behind it and in some cases is great enough to cause lighter cars to swerve. This effect also enables a kite to stay in the air.

Laboratory Exercise 32. Hold a lighted match behind a card about two inches square, and blow hard against the other side of the card. Explain the results.

Streamlining of a plane. Anyone who is familiar with the modern trend in automobile design must realize the importance of streamlining. The old square-cut automobiles have been replaced by automobiles equipped with graceful lines and sweeping curves. Streamlining of an object involves the elimination of burbles. It has already been shown that turbulence forms when streamlines are diverted abruptly. Therefore, airplane and automobile designers have found it necessary to devise streamlined bodies that reduce drag by eliminating the turbulence. This is especially important in airplane design.

The solution of the problem of streamlining was discovered by means of a *wind tunnel,* which subjects variously shaped objects to a strong blast of air. Streamers of smoke are introduced into the air in the wind tunnel to enable research workers to observe the paths followed by the air in flowing over and around surfaces.

The effect of a flat plate on streamline flow is shown in Figure 83 and represents the condition for greatest drag. The shape that produces the least drag has been developed by equipping both sides of the plate with rounded sections which enclose the areas of turbulence (Fig. 84). When tested in a wind tunnel, it has been found that the streamlines flow smoothly over a surface of this type without turbulence. The general streamlined shape is that of a falling raindrop, which is similar to the shape of the fuselage of a modern airliner.

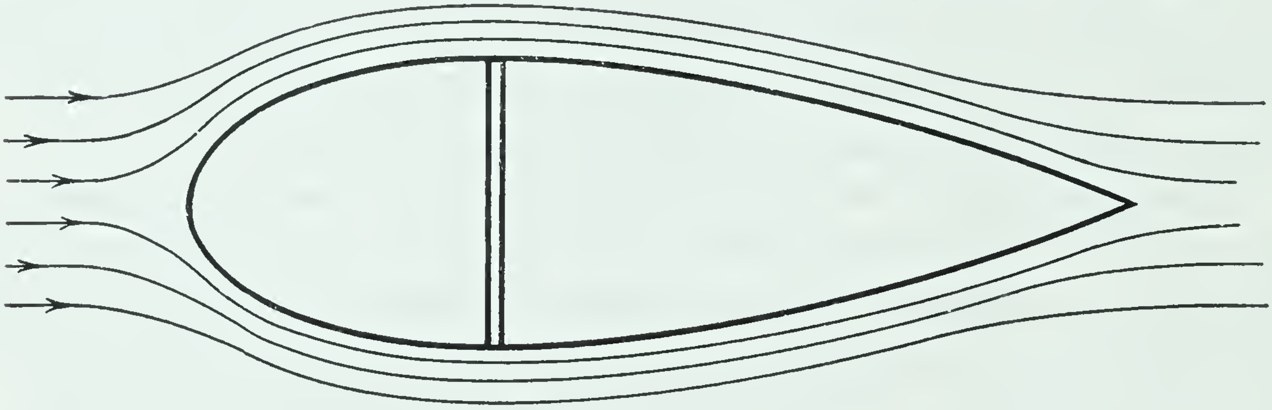


Fig. 84

To better illustrate the importance of streamlining, compare *A* and *B* in Figure 85. The first represents an older type of wing strut and the second a new type. The circular type produces approximately fifteen times as much drag as the streamlined strut.

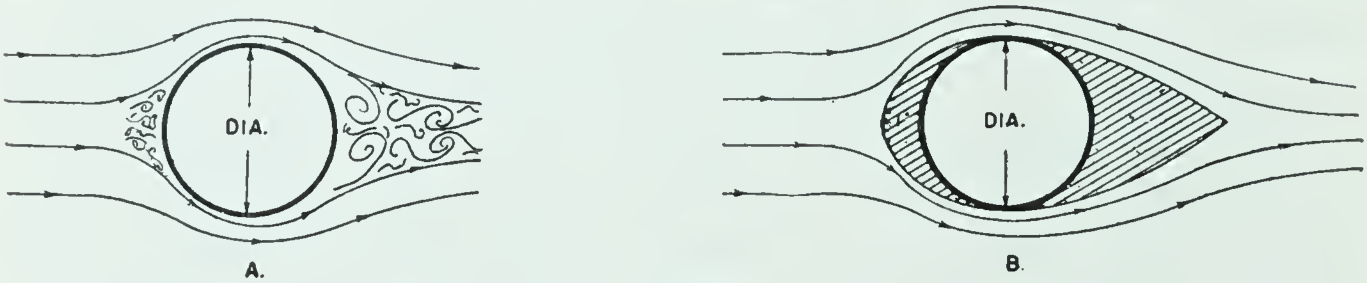


Fig. 85

It requires energy to divert a streamline, and the greater the diversion, the greater the amount of energy required. Consequently, in airplane manufacture and design, the diversion is minimized in order that the airplane's energy may be conserved for more useful purposes.

Bernoulli's principle. A Swiss mathematician by the name of Bernoulli discovered that, as the velocity of a fluid increases, the static pressure perpendicular to the direction of flow decreases. Whenever a fluid flows past a constriction in a pipe, it must flow faster through the constricted portion of the pipe. This may be shown theoretically as follows: Let the mass of fluid which flows past point P_1 (Fig. 86) in one second be designated by M_1. Then

$$M_1 = A_1 D_1 d \tag{1}$$

where A_1 represents the area of cross-section of the pipe, D_1 is the distance traveled by a particle of fluid in one second, and d the density of the fluid. In like manner the mass of fluid M_2 flowing past point P_2 in one second is given by

$$M_2 = A_2 D_2 d \tag{2}$$

where A_2 is the area of cross-section of the pipe at this point, D_2 is the distance traveled by a particle of fluid in one second, and d is the density of the fluid. It is obvious that the mass of fluid flowing past any point in the pipe in one second must equal the mass flowing past any other point during the same interval of time. Therefore

$$M_1 = M_2 \tag{3}$$

and, since density may be considered to be constant:

$$A_1 D_1 = A_2 D_2 . \tag{4}$$

Since velocity is defined as distance traveled in one second, velocities may be substituted for distances in equation (4), which then becomes

$$A_1 V_1 = A_2 V_2 . \tag{5}$$

If A_1 is greater than A_2, it follows that V_2 must be correspondingly greater than V_1. This increase in velocity in the constricted region of the tube results in a decrease in lateral pressure at this point which may readily be detected experimentally. First connect small vertical

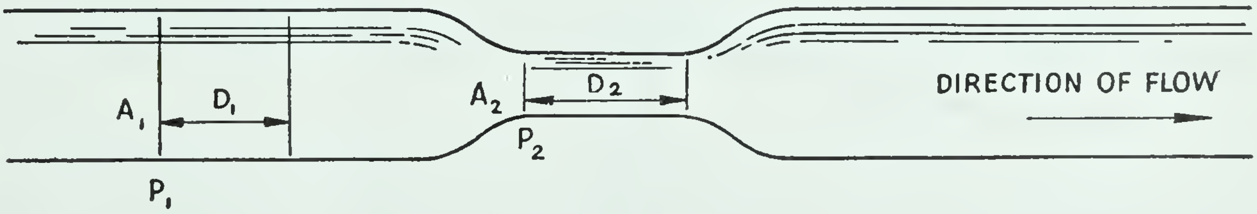


Fig. 86

tubes of the same height to the tube at points *A, B,* and *C* (Fig. 87). Now if natural gas or some other combustible gas is forced through the main tube and the gas lighted as it leaves the jets at *A, B,* and *C,* the flames formed will be of different heights. The flames at *A* and at *C* will be higher than the flame at *B*. This difference signifies that the static pressure at *B* is less than that at either *A* or *C*. This change of static pressure with velocity occurs regardless of whether or not the fluid is confined to a tube. Consequently the increased velocity of air as it is diverted about a streamlined body results in a decreased pressure. This decrease in pressure over the surface of an airplane wing is responsible for a part of the lift that raises a plane from the ground and will be discussed more fully in connection with the airfoils.

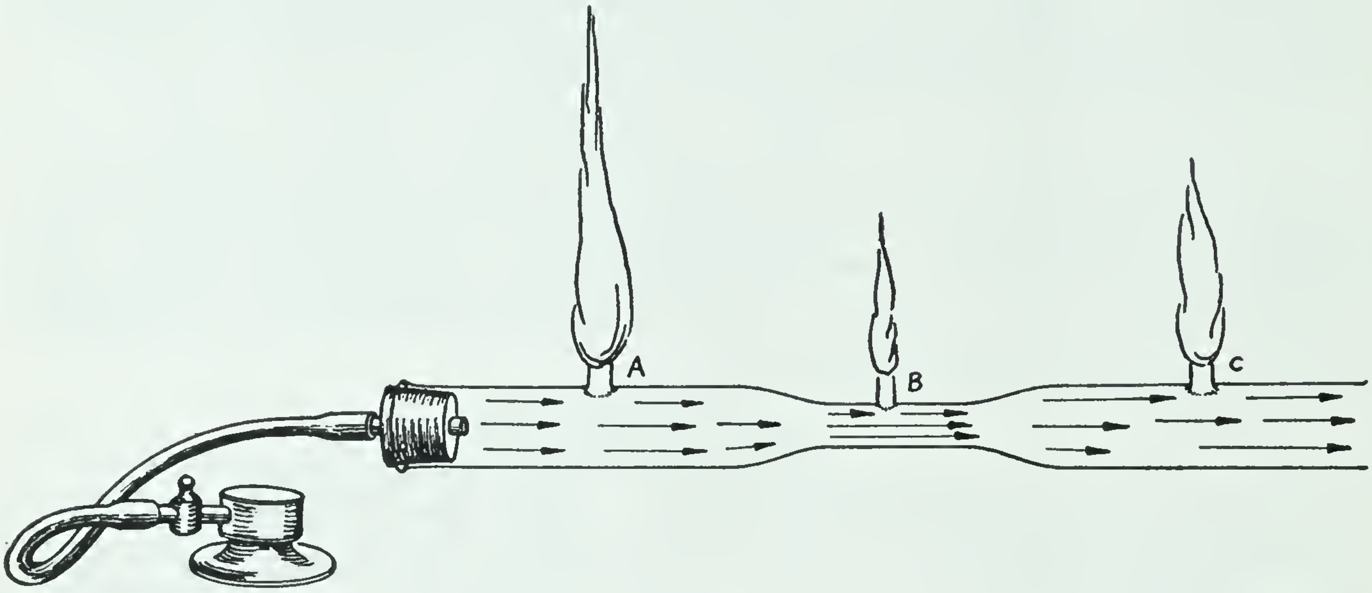


Fig. 87

The venturi tube. The tube shown in Figure 87 is called a *venturi* tube. In order to show the application of Bernoulli's principle

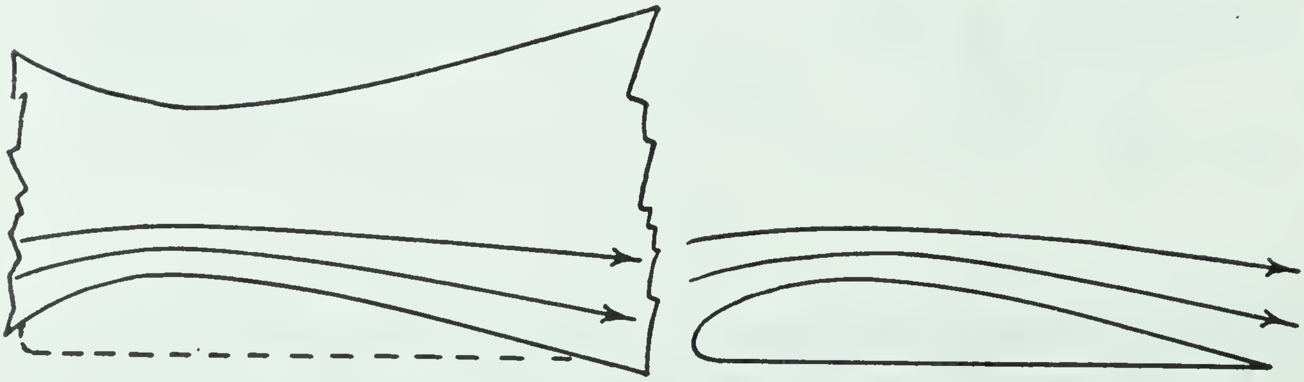


Fig. 88. Cross section of a venturi tube

to the airplane, a venturi tube which varies slightly in cross-section must be used (Fig. 88). As the air rushes through the tube in the direction indicated by the arrows, its velocity increases, thus decreasing the lateral pressure. Moreover, the streamlines tend to follow the contours of the tube. If the walls of the tube are separated and one is finally removed, the principle of the venturi tube is still manifest. Figure 89 represents the surfaces created by the removal of one half of a venturi tube. These surfaces assume the shape of an airfoil and are typical of the cross-section of an airplane wing or of a propeller blade.

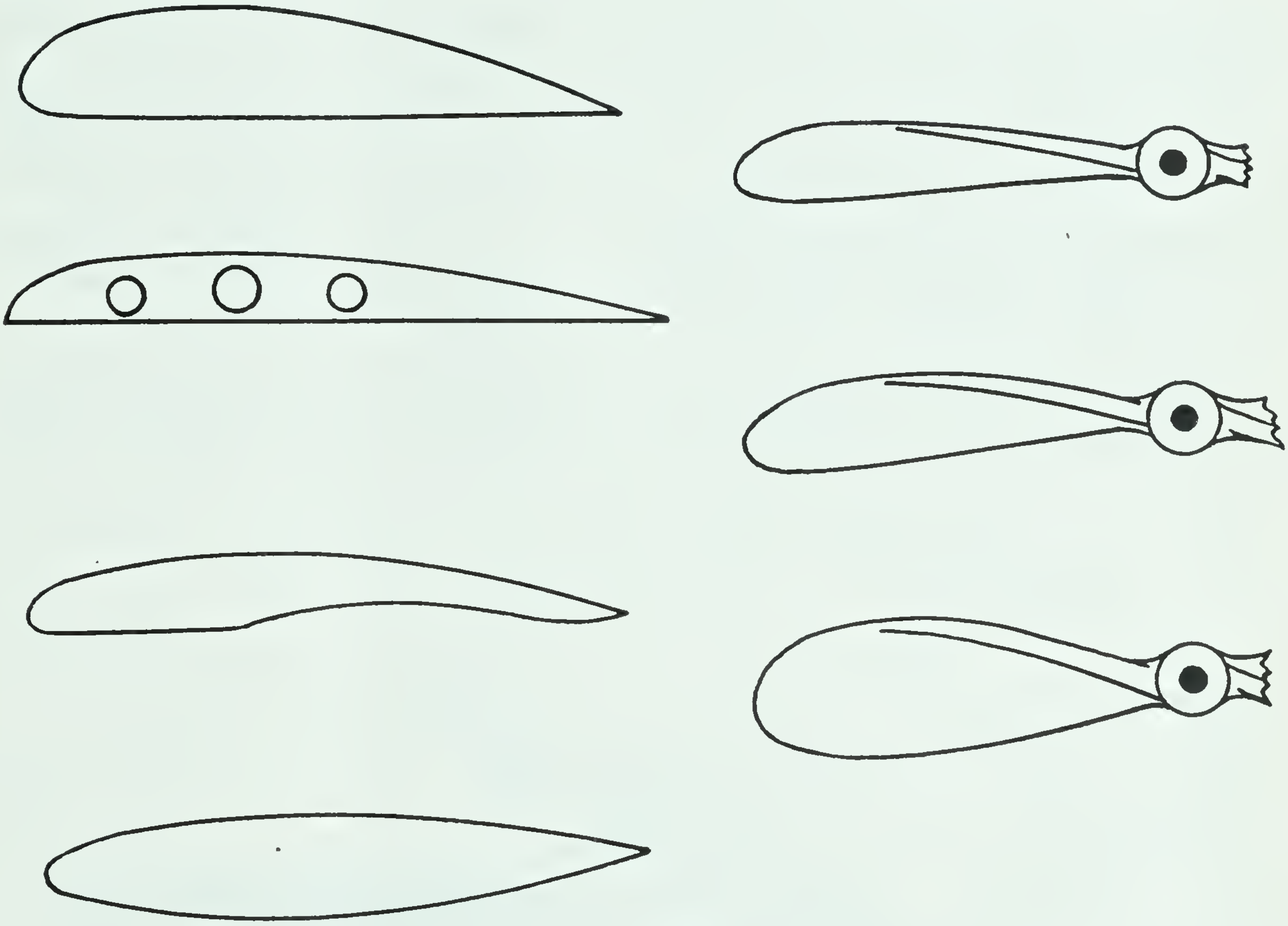


Fig. 89

Airfoils. Any part of an airplane so designed that air flowing around it produces useful motion is called an *airfoil*. This definition includes the wings, propeller, and tail surfaces of the airplane. Streamlines, in passing around an airfoil, both beneath and above it, reach the rear of the airfoil at the same time. It is obvious then that those streamlines which travel over the top of a typical airfoil also travel a greater distance and must move with greater velocity. Associated with this increase in velocity is a decrease in lateral pressure on the curved surface.

The conception of diminished lateral pressure due to increased velocity is not difficult to grasp. A powerful stream of water propelled horizontally is not easily penetrated by objects dropped into it from above. Thus a surface over which such a stream of water is flowing is shielded from the falling objects. Assuming that the falling objects represent air molecules moving toward a surface, an increase in the horizontal velocity of the air immediately above the surface will, likewise, prevent the normal pressure of the air from exerting its complete force on the surface. Returning now to the airfoil (Fig. 89), the streamlines along the lower surface protect that surface less from the normal air pressure than do the streamlines of greater velocity on the upper surface. This difference in pressure produces a part of the lift imparted to a moving airplane wing.

The results of experimental studies of the distribution of air pressure on an airplane wing show that all parts of the upper surface of a wing are not subjected to the same pressure. Figure 90 illustrates the method used in determining the pressure on wing surfaces. The small tubes contain a liquid which, if the wing were not subjected to an airflow, would stand at the same level in both vertical arms of each tube. However, when an airflow is directed over the upper curved surface (upper *camber*) of the wing, the pressure be-

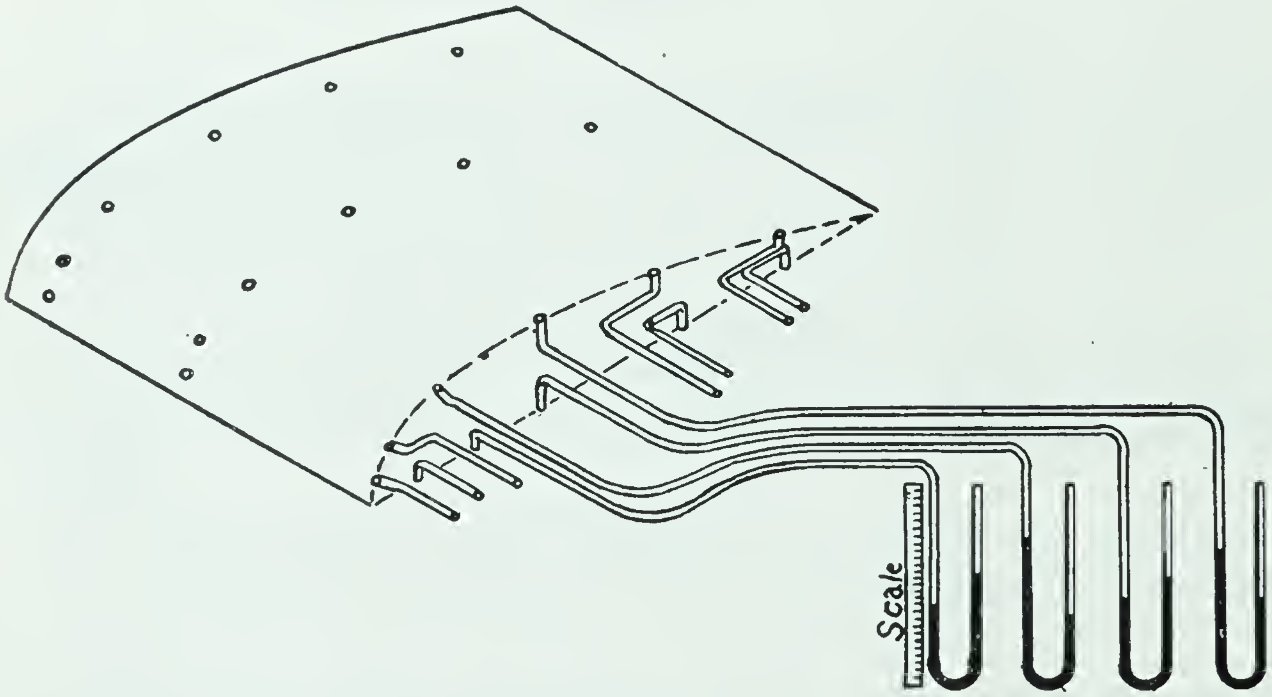
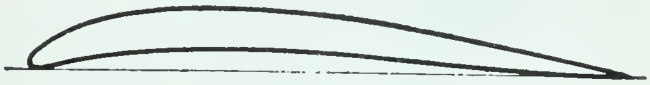
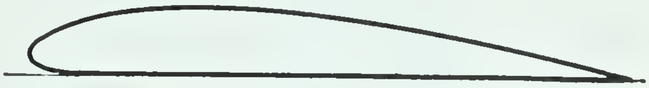


Fig. 90

comes less than atmospheric pressure. As a result, the liquid rises in the arm of the tube nearest the wing and descends in the open arm that is subjected to normal atmospheric pressure. Similarly, the air pressure on the lower surface (lower *camber*) of the wing causes the liquid to lower in the arm of the tube nearest the wing and rise in the arm subjected to normal atmospheric pressure. The difference in the level of the liquid between the two arms of a tube may be used to determine the difference in pressure between any point on the upper wing surface and the atmospheric pressure.


ALBATROSS: CONVEX AND CONCAVE


CLARK Y: CONVEX AND FLAT

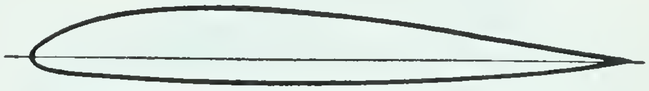

M-6: BOTH SURFACES CONVEX

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Fig. 91

In addition to camber of the upper wing surface, some airplane wings, such as the Albatross (Fig. 91), are so designed that they have a concave lower surface. Such construction permits streamlines to curve upward around this concavity and exert a positive pressure against the lower surface of the wing. While this tends to increase the lift somewhat is also increases the drag or retarding force of the airstream.

Laboratory Exercise 33. Cut a piece of cardboard two inches square and stick a common pin through the center. Mount the cardboard and pin on a spool with the pin extending into the hole in the spool. Hold the spool vertically and try to blow the cardboard off by blowing through the hole in the spool. Repeat, holding the spool horizontally. While blowing hard, tip the head down so that the spool is again vertical but with the cardboard at the bottom. Explain the results. (See Figure 92 on page 162.)

Exercise 34. Can one streamline move faster than another? Discuss.

Exercise 35. Prepare a comprehensive report on wind tunnels.

Problem 3. What forces act on an airplane during flight?

A plane in straight line (rectilinear) flight is constantly subjected to conflicting forces that determine its direction of motion, its speed, and its acceleration. These forces are the result of air resistance, the gravitational pull of the earth, the lifting effect of the airfoils (wing and tail surfaces), and the thrust developed by the propeller. Since each of the forces just named is *directional,* it is also a *vector* and can be represented graphically as such.

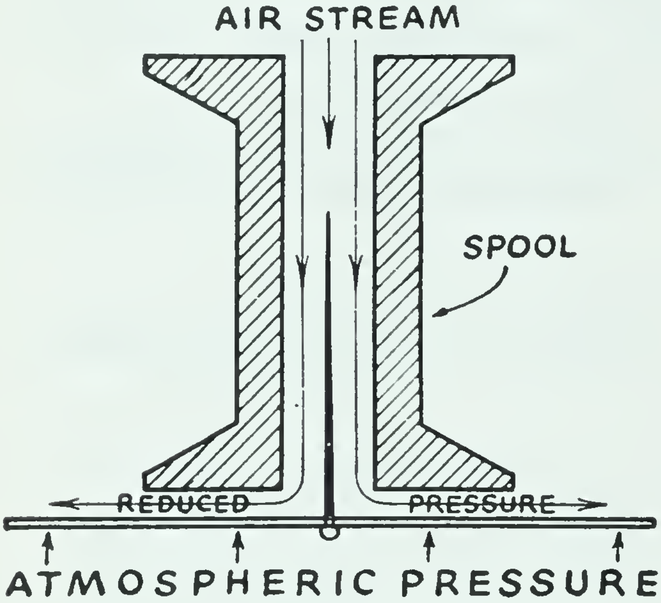


Fig. 92

Center of gravity of an airplane. And airplane is essentially a heavier-than-air machine. It is naturally attracted to the earth's surface by the earth's gravitational pull. The weight of the airplane, however, is distributed unevenly throughout its length and breadth (Fig. 93). If the length of the plane be represented as a lever with the various individual weights suspended from it, there will be a point, *A*, somewhere along the bar about which all of the weights balance (Fig. 94). In other words the sum of the moments of forces tending to produce clockwise rotation about *A* will just equal the sum of the moments of forces tending to produce counterclockwise rotation about the same point. If the plane now be considered from the front, there will be a point along the lateral axis (wing-tip to wing-tip), about which the moments of forces will also balance (Fig. 95). This point is the location of *A* with respect to the wing tips. The point *A* is the place at which the mass of the airplane appears to be concentrated. In other words, if the

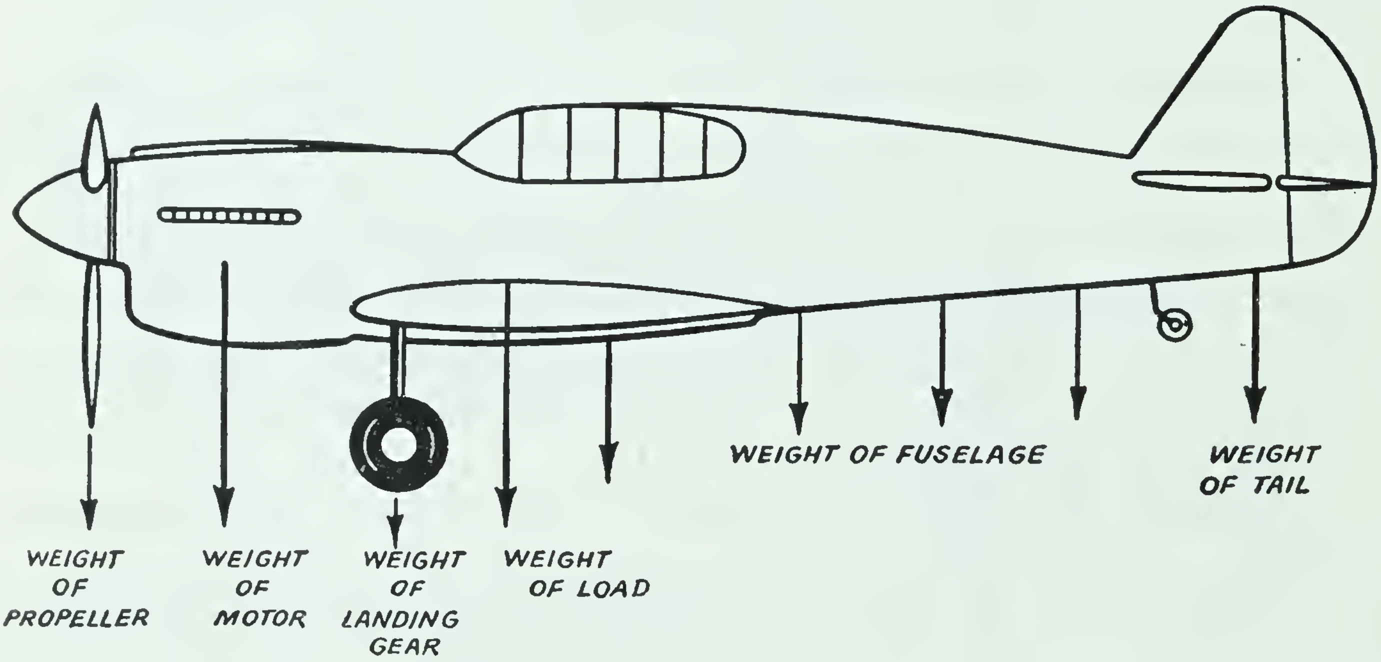


Fig. 93. Distribution of weight in an airplane

airplane is suspended from a cable attached at *A,* the plane will not rotate in any direction but will be perfectly balanced. This point of balance in an airplane is called the plane's *center of gravity,* and the entire weight of the plane acts as if it were concentrated at that point.

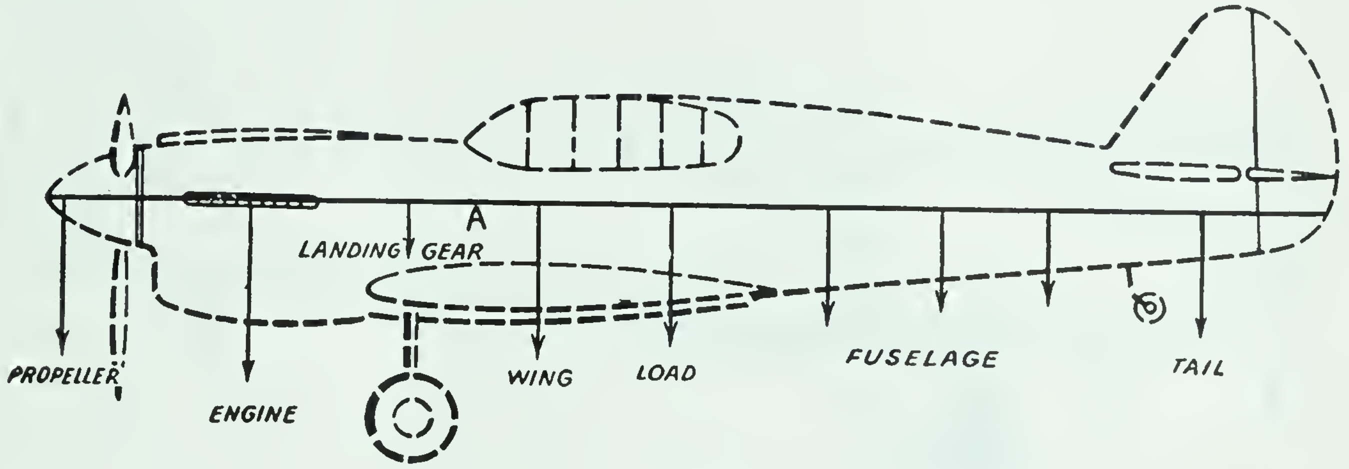


Fig. 94

In all forthcoming discussion the center of gravity will be referred to as *C. G.* The gravitational pull of the earth is represented by a vector *AG* perpendicular to the earth's surface and passing through the center of gravity of the plane (Fig. 96).

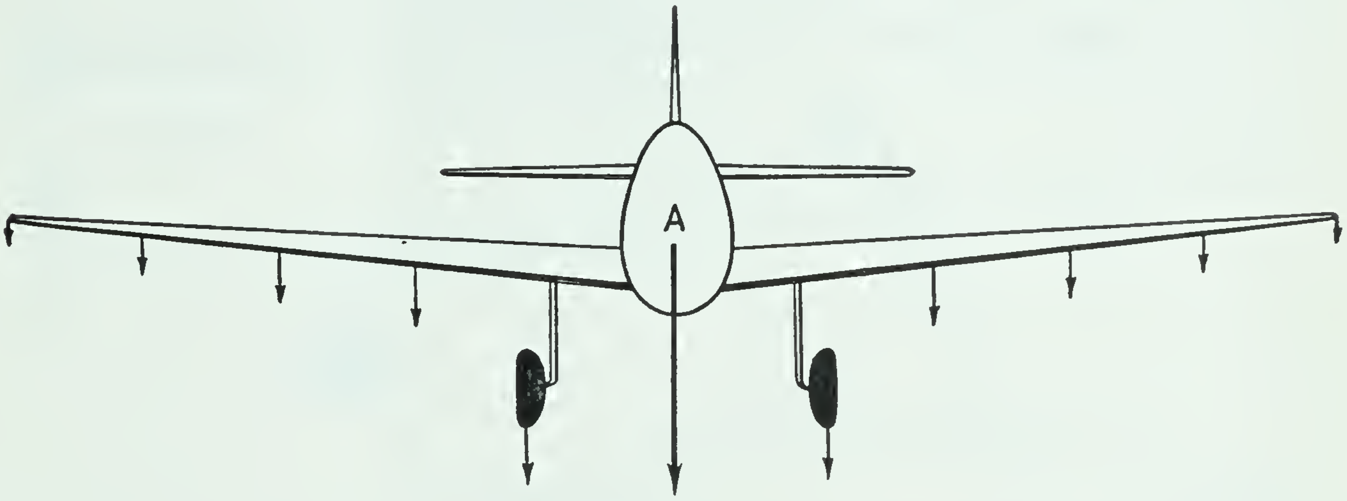


Fig. 95

Exercise 36. What would be the effect on a cargo plane if the cargo should suddenly shift backward?

Exercise 37. If a plane has two fuel tanks, one in each wing, how is the center of gravity affected if one tank is emptied entirely before fuel is used from the other?

Center of pressure. The lift of a wing results from differences in air pressure above and below the wing. It is a common notation to call the pressure above the wing a negative pressure and that below the wing a positive pressure. Pressure is negative or positive depending on whether it is less or greater respectively than atmospheric pressure. However, the pressure distribution is not uniform over the wing surface. The portion of the wing directly behind the propeller in a single-engined plane creates less lift than do the areas to the right or left of it. Likewise, a tapered wing produces less lift at the wing tips than it does where the wing is broader. All of the lifting forces, however, act as if they originate from a point near the middle of the wing. This point is called the *center of pressure* of the wing and henceforth will be referred to as *C. P.* Unlike the center of gravity, the *C. P.* has a tendency to shift forward on the wing as the angle of

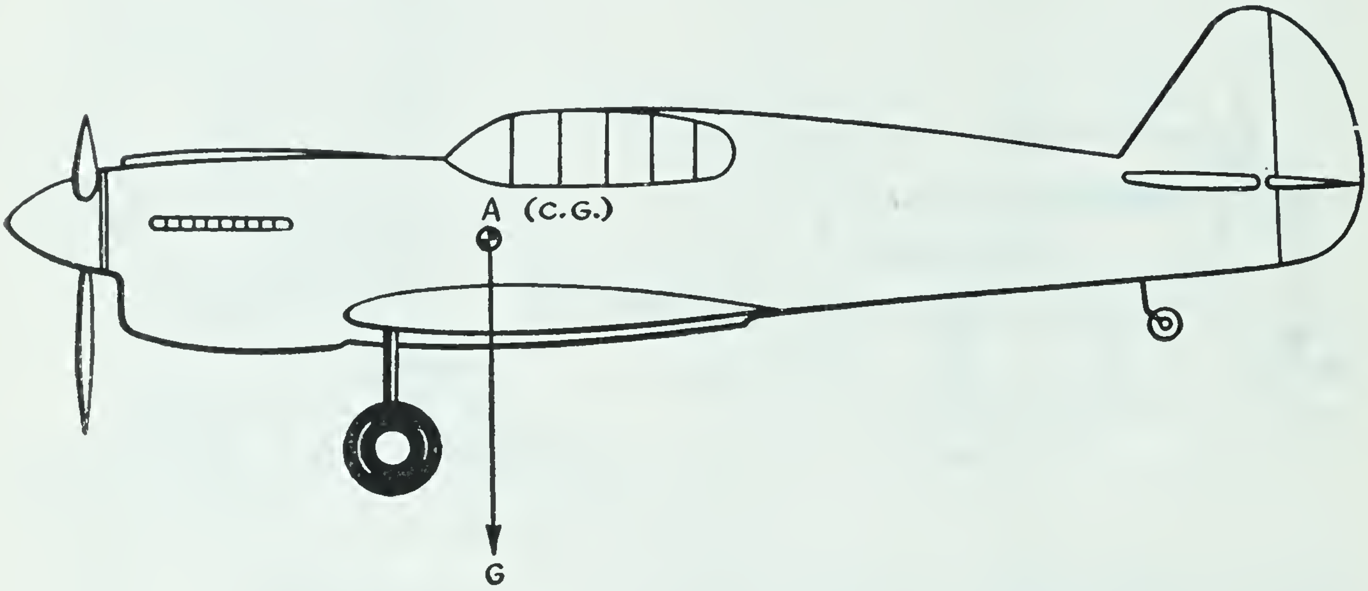


Fig. 96

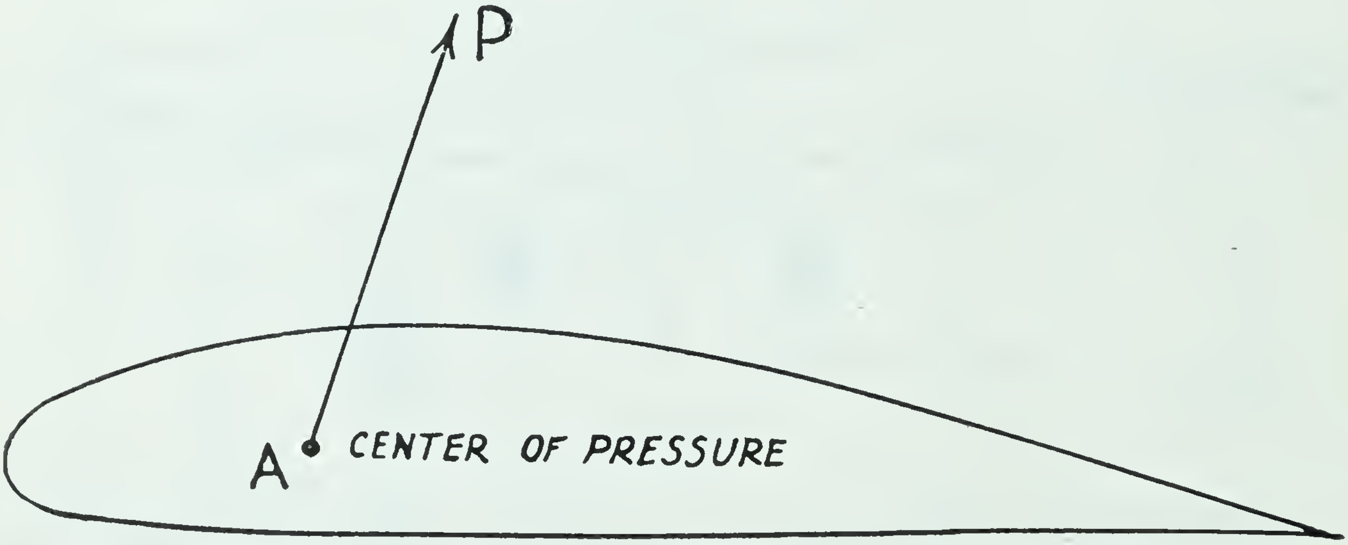


Fig. 97. Location of the center of pressure of a wing. The center of pressure moves forward or backward with changes in angle of attack.

attack increases and to shift backward on the wing as the angle of attack decreases. The angle of attack of a wing is the angle that the wing makes with the relative wind, which in turn is always parallel to the direction of motion of the plane with respect to the air. Airplanes are usually so designed that under normal flight the *C. P.* always stays behind the *C. G.* This is done to make the airplane longitudinally stable.

Components of the wing force. The total aerodynamic action on the wing may be represented by a vector *AP* drawn through the *C. P.* (Fig. 97). It is apparent from the figure that the force acts in an upward and slightly backward direction. This slanting force is inconvenient to work with since it represents both drag and lift, due to its direction. It is essential, therefore, that the total wing force *AP* be resolved into its vertical and horizontal components. This requires a parallelogram of forces in which *AP* is the diagonal of the parallelogram. From points *A* and *P* draw vertical and horizontal lines, which intersect at *L* and *D* (Fig. 98). The vector *AL* now represents the lift component of the aerodynamic action of the wing known as sustentation, and the vector *AD* represents the drag component. The two forces *AL* and *AD* produce the same result as the single force *AP*.

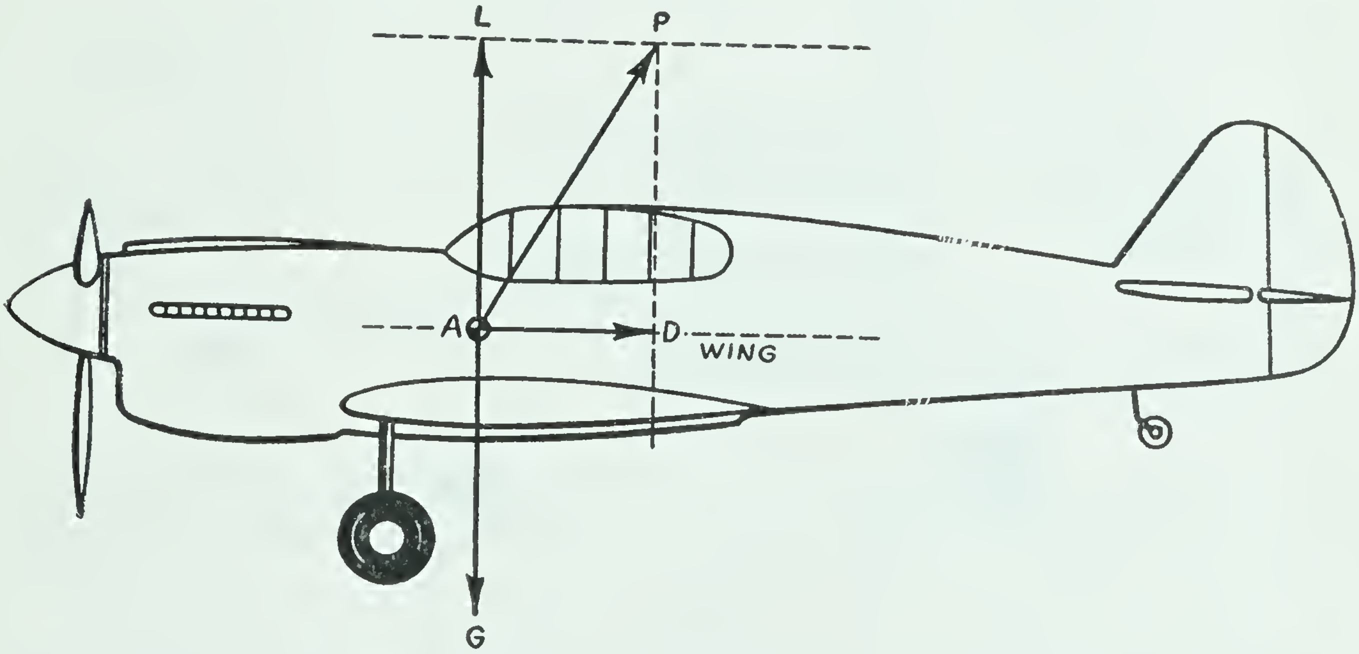


Fig. 98

Total drag on an airplane. It has already been observed (Fig. 98) that the air pressure on the wing of an airplane causes a drag that opposes the plane's forward motion. It must be remembered, however, that not all portions of a plane act as airfoils. The fuselage, landing gear, struts, radio antennas, and other parts are responsible for *parasite drag* caused by air resistance. Since this parasitic drag acts in the same direction as the wing drag (opposing the direction of motion), the two forces (vectors) add together and act as one force (Fig. 99). This may be represented in equation form as:

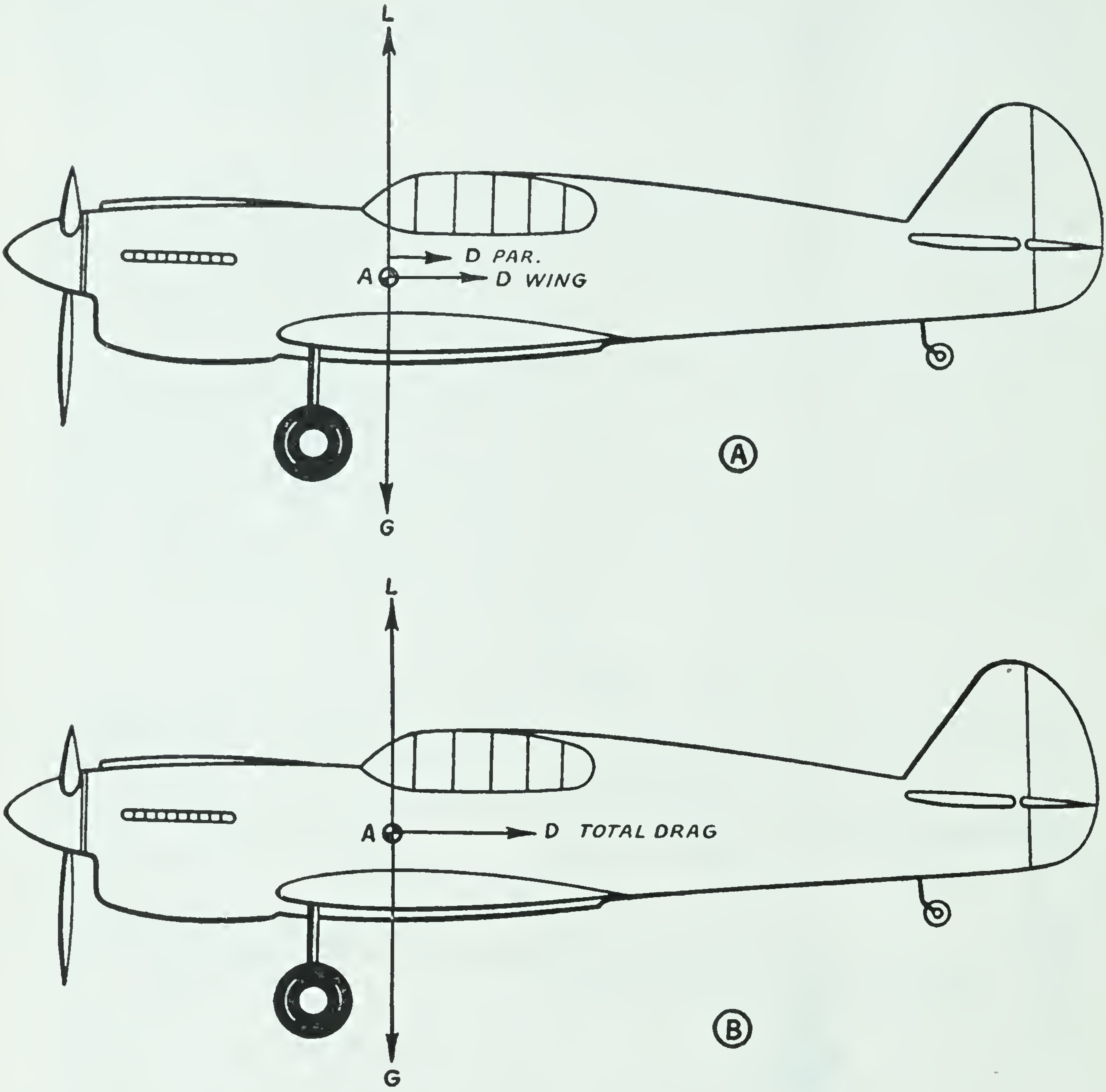


Fig. 99

$$\text{Total Drag} = \text{Wing Drag} + \text{Parasite Drag—or,}$$

$$D_t = D_w + D_p.$$

These two components of the total drag will be considered much more in detail in a later topic in connection with the solution of problems.

One of the principal causes for wing drag is the reaction that takes place at the wing tips. The pressure of the air above the wing is negative in sense, and the pressure beneath the wing is positive. As the air passes over the wing tips it is deflected downward and toward the fuselage (toward region of still lower pressure). On the other hand, the air that passes beneath the wing tips moves away from the fuselage and some air sweeps upward around the tip of the wing. These air movements result in a swirl of air in the form of eddies behind the wing tips and along the trailing edge of the wing toward the fuselage (Fig. 100). (Similarly, vortices are formed about the tips of the tail planing surface.) Since it requires energy to form these vortices or eddies, they constitute a *drag* that brings about a reduction in lift.

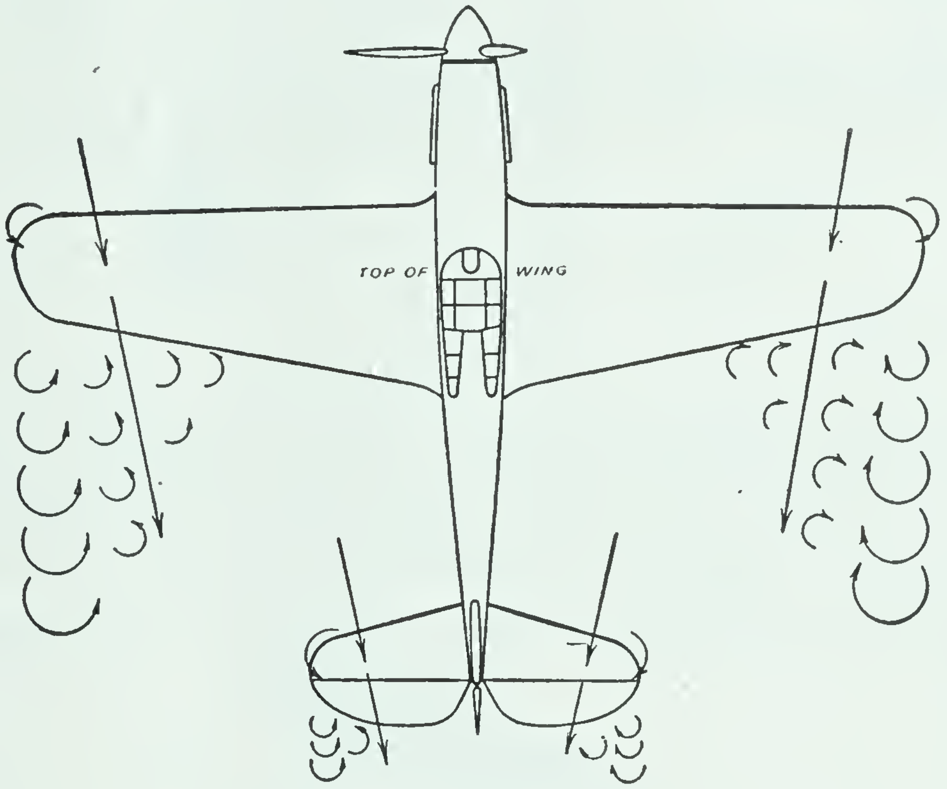


Fig. 100

Experiments show that the narrower the wing, the smaller the loss in lift caused by wing-tip vortices. On the other hand, the greater the wing area, the greater the lift will be. From these facts it is apparent that in order to increase lift and reduce drag, a long narrow wing must be used. The ratio of the span of a wing to its average chord (width) is called the wing's *aspect ratio*. It would seem then that as the aspect ratio of a wing increases, its desirability increases. Theoretically, this reasoning is correct, but in practice it is necessary to limit the aspect ratio to increase the strength of the wing. Whereas the aspect ratio of some gliders may be as high as twenty (the wing is twenty times as long as it is wide), the aspect ratio of airplanes ranges from three (for racing planes) to about eight (for commercial planes). Airplanes are limited to relatively small aspect ratios because of the heavy loads they carry and the consequent strain on the wings.

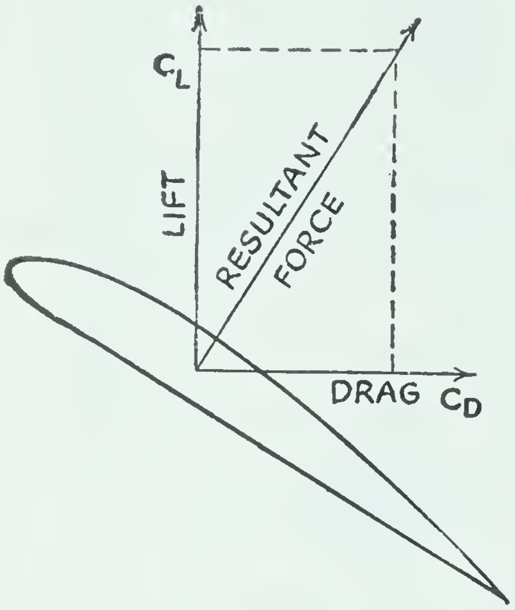


Fig. 101

Propeller thrust. So far, three forces that act on a plane have been considered: the forces of gravity, lift, and drag. Gravity and lift oppose each other, and similarly drag has a counter force that opposes it. This forward *thrust* is a result of the rotation of the propeller, which is essentially an airfoil, and as such has the characteristics of both lift and drag. The resultant force of the propeller does not act in a line parallel to the direction of flight. Instead it acts at an angle much as the aerodynamic force of the wing. Consequently, the aerodynamic force of the propeller must be resolved into component forces of lift L and drag D (Fig. 101). The drag of a propeller is called the propeller *torque* component and will be discussed later as a factor affecting stability. The rotation of the propeller by the engine is responsible for the relative motion of airfoil and air.

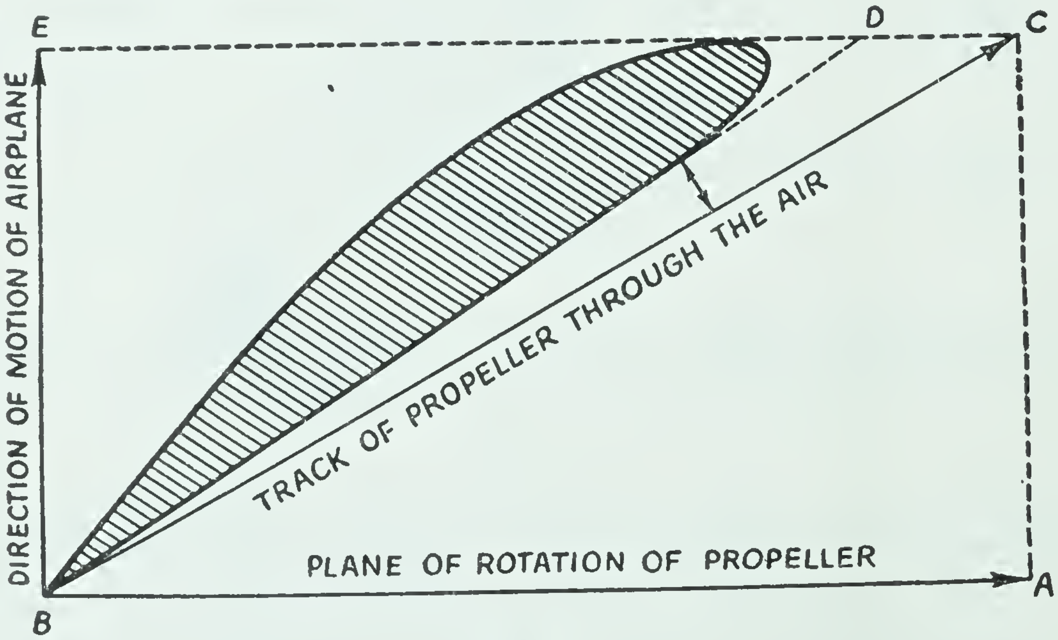

E
D
C
DIRECTION OF MOTION OF AIRPLANE
TRACK OF PROPELLER THROUGH THE AIR
PLANE OF ROTATION OF PROPELLER
B
A

Fig. 102

Within certain limits, as the angle of attack of the propeller blade is increased, so is the thrust. However, the propeller blade, because of both its forward motion and rotation, moves in a path which is the resultant of the other two. The line AB (Fig. 102) represents the path that a section of a propeller would take if it were revolving, but not moving forward. The line *BE* represents the motion of the propeller if it moves forward without rotation. The line *BC* represents the path followed as the result of both motions. From this, it is apparent that the effective angle of attack, instead of being angle *ABC* is actually angle *CBD*.

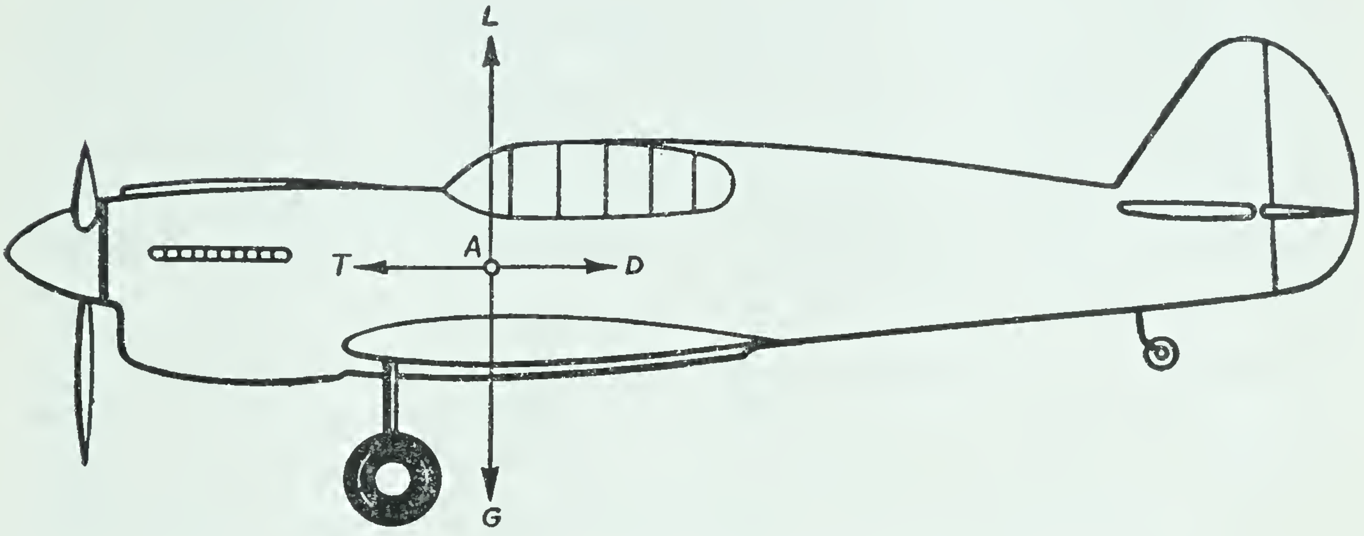


Fig. 103

Forces on a plane in straight level flight. If a plane is in straight level flight, accelerating neither positively nor negatively, all of the forces acting on it are in equilibrium. This signifies that the lift and weight are equal and opposite and also that the thrust just equals the drag (Fig. 103). The figure shows the forces as all acting from the *C. G.*, which is an indication of *balanced forces*. This situa-

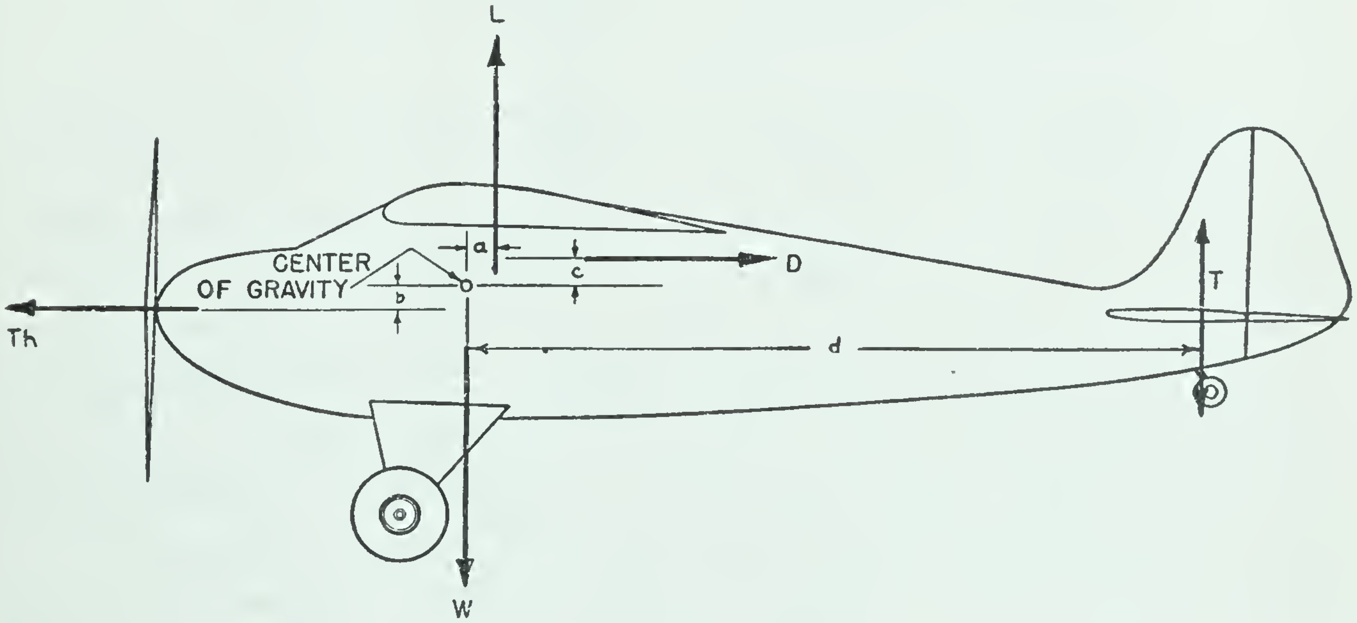


Fig. 104. Forces in flight

tion, however, is not necessarily true of all airplanes. In some planes the forces act from points other than the *C. G.*, but with the *C. G.* as the pivot for those forces. If this be the case, equilibrium is obtained by *balanced moments* (Fig. 104). A moment of force is obtained by multiplying the force by the perpendicular distance through which it acts. In the figure, *Dc* is a moment that tends to pull the nose of the plane up; *Th.b* also tends to pull the nose up; *La* tends to pull the tail up and the nose down; and *Td* tends to pull the nose either up or down depending on the setting of the tail-control surfaces. For the airplane to be in equilibrium, it is apparent that the resultant of all the moments must be zero. It is necessary, therefore, to consider those moments that tend to tip the nose down as being *negative* and those moments that tend to tip the nose up as being *positive*. In order, then, that the plane be in equilibrium, the following relationship must exist:

$$Dc + Th.b - La \pm Td = 0$$

It is also apparent that the thrust must still equal the drag and the lift equal the weight of the plane plus the downward tail load, or:

$$\text{Thrust} - \text{drag} = 0 \quad \text{—and}$$

$$\text{Lift}_{\text{(wing)}} = \text{Weight} + \text{downward tail load}$$

The following discussions will be illustrated as if the forces all act through the *C. G.* However, it is well to remember that such an arrangement of forces rarely occurs and is the exception rather than the rule. For our purpose a great deal of complexity may be avoided by dealing with balanced forces rather than with balanced moments.

Forces acting on a climbing airplane. As a plane climbs, the resultant aerodynamic force slants back further than it does in straight level flight. When this force is resolved into its component forces, perpendicular and parallel to the relative wind, the result is as shown in Figure 105. Vector *AP* represents the resultant force, *AL* the lift component (perpendicular to the relative wind), and *AB* the drag component (parallel to the relative wind). Similarly, if *AG* is resolved into forces perpendicular and parallel to the relative wind, *AG* will be equal and opposite to *AL*, if the plane is flying in uniform straight line flight. The other component of the gravitational pull, *AC*, constitutes an added drag that must be overcome by the propeller thrust. If *AB* now represents wing drag, *BC′* (equal to *AC*) the drag due to gravitational force, and *C′D* the parasitic drag, the total drag may be represented by *AD*.

Contrary to common belief, the only difference between a uniform climb and level flight is that a *backward component of gravitational force* (weight) is *added* to the aerodynamic drag forces existing in level flight. If there is enough excess power available so that the thrust of the propeller can provide just exactly enough additional force to overcome this component, the plane will climb at the same speed and the same angle of attack as in level flight. This is often referred to as a climb at cruising speed, and is the best for cross-country procedure, unless there is need to gain altitude at a faster rate per unit of horizontal distance in order to clear obstacles.

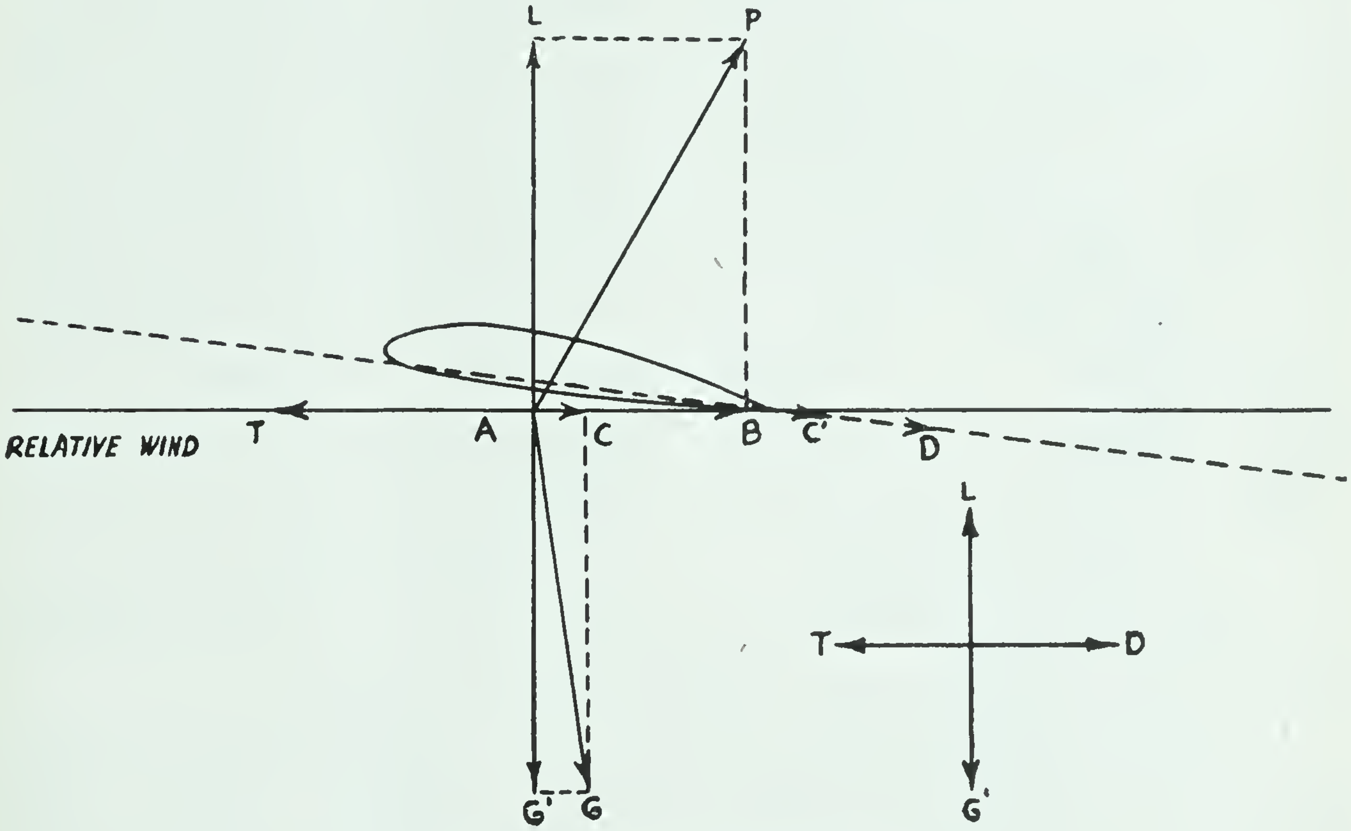


Fig. 105. Forces in climbing

In most cases, however, the pilot of a light airplane will wish to gain altitude faster and will put the airplane into such an attitude that even full throttle will not provide the additional thrust needed to overcome the backward component of gravity. When this happens, speed is reduced, and the angle of attack has to be increased to provide the necessary lift at the reduced speed. This increase in angle of attack will further increase the drag, and may slow down the plane to the point where, although not actually stalled, it is mushing along in level flight although in a climbing attitude. A climb, therefore, is a compromise of various factors. If it is necessary to increase the velocity (accelerate positively) in a climb, then a considerable reserve of power must be available to provide the added thrust necessary for the acceleration and at the same time to overcome the added drag produced by increased speed.

Forces acting on a gliding airplane. If a plane is in a glide, the nose is down, and it is assumed that the engine is dead or idling. In other words, no thrust is obtained from the propeller. With the nose down, the resultant aerodynamic force is approximately vertical. When this force is resolved into the component forces of drag and lift and then combined with the parasite drag and the force of gravity, it seems at first glance that only three forces are acting on the plane (Fig. 106B). However, since the airplane is moving forward as well as downward, it must have a thrust. This thrust may be obtained by resolving the force of gravity into two forces, one opposing the lift (*AG′*) and the other opposing the drag (*AT*).

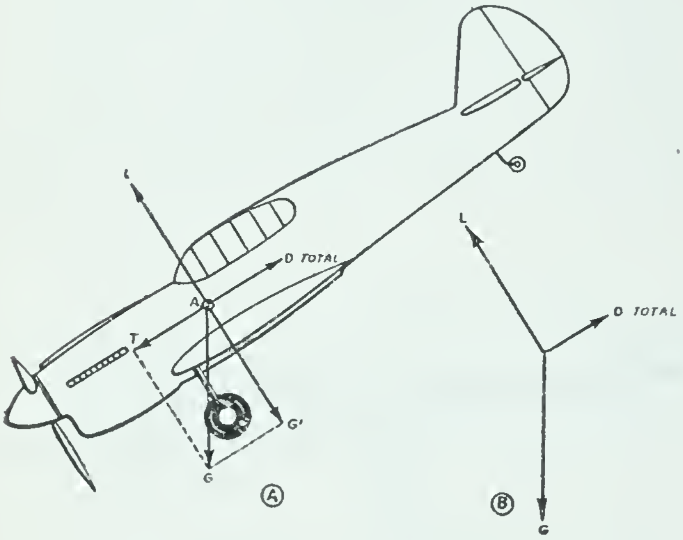


Fig. 106. Forces in gliding

It must be realized that, as a plane first starts to glide, it accelerates. This means that the thrust component of gravity is greater than the total drag of the airplane. However, as the velocity of the airplane increases, the drag increases until it equals the thrust. Thus the forces again reach the state of equilibrium.

Exercise 38. Report on the wing span of modern planes.

Problem 4. What factors determine the lift and drag on an airplane?

The design of the wings of modern airplanes has been developed as a result of years of painstaking experimentation, involving the extensive testing of models in wind tunnels. Such experiments have proved that several factors influence the lift and drag of an airfoil.

Wing factors that affect lift. In the first problem in this unit the *slug* was defined as the unit of air mass commonly used in determining lift and drag. A slug of air is a mass that weighs approximately 32.2 pounds. The density of the air at sea level under standard conditions is about .002378 slugs per cubic foot. It has been found from wind-tunnel tests that *the lift of an airfoil varies directly as the density of the air.* For any constant velocity as the density of the air increases, the lift increases, and conversely. Thus, if air of sea-level density produces a lift of 1000 pounds on a plane at a certain velocity, then air just half as dense will produce a lift of only 500 pounds at the same velocity. Likewise, air of two-thirds this density will produce a lift only two-thirds as great and so on. Density is always given in terms of slugs per cubic foot and is represented in equations by the symbol ρ (the Greek letter "rho," pronounced rō).

The following table gives the density of the air in slugs per cubic foot for different altitudes. In computations in aerodynamics one half of the density $\left(\frac{\rho}{2}\right)$ is used instead of the density ρ, since air of this density theoretically results in unit pressure on the wing at unit air velocity.

TABLE I

Variation of Air Density with Altitude

Altitude in feet	Density in slugs per cubic foot (ρ)
0	.002378
1000	.002309
2000	.002242
3000	.002176
4000	.002112
5000	.002049
6000	.001987
7000	.001928
8000	.001869
9000	.001812
10,000	.001756
11,000	.001701
12,000	.001648
13,000	.001596
14,000	.001545
15,000	.001496
20,000	.001267
30,000	.000889

It is apparent from the table that the air at the 20,000-foot level is only about one half as dense as sea-level air.

Wind-tunnel experiments also show that, if two airfoils are alike in all respects except size, the airfoil with the largest surface area will produce the greatest lift. An airfoil of twice the area produces twice the lift. From this it is evident that *the lift of an airfoil varies directly as the surface area.* Surface area is represented by the letter S.

Still another factor influencing lift is the velocity of the air relative to the airfoil. As the air velocity increases, the lift increases, and conversely. It has been found experimentally that, if the air velocity is doubled, the lift becomes four times as great. Likewise, if the air velocity is three times as great, the lift is nine times as great, and so on. It is obvious, then, that *the lift of an airfoil varies directly as the square of the velocity.*

In mathematical computations of lift, the *airspeed* is usually given in miles per hour; whereas the velocity (V) must be in feet per second. For convenience in making transformations, velocity in feet per second may be obtained by multiplying airspeed by 1.467, and airspeed in miles per hour may be obtained by multiplying velocity by .682.

$$V = 1.467A \qquad A = .682V$$

The following table will be of value in working problems.

TABLE II

Conversion of Airspeed to Velocity

Airspeed in m.p.h.	Approximate velocity in ft./sec.	V^2 in ft./sec.
30	44	1936
40	59	3481
50	73	5329
60	88	7744
70	103	10,609
80	117	13,689
90	132	17,424
100	147	21,609
125	183	33,489
150	220	48,400
175	257	66,049
200	293	85,849

It is now possible to write an algebraic relationship for the lift:

$$L \propto \frac{\rho}{2} SV^2. \tag{1}$$

This relationship holds true only if the angle of attack remains constant. The proportionality sign ($\propto$) can be removed and an equals sign ($=$) inserted in its place if a constant of proportionality (K) be inserted. The equation now becomes:

$$L = K \frac{\rho}{2} SV^2 \tag{2}$$

In this equation L is in pounds, $\frac{\rho}{2}$ in slugs per cubic foot, S in square feet, and V in feet per second. If equation (2) is solved for K, the equation obtained is:

$$K = \frac{L}{\frac{\rho}{2} \quad SV^2}. \tag{3}$$

Assume now that one half the density of the air, the surface area, and the velocity are all unity (*i.e.*, $\frac{\rho}{2}$ equals one slug, surface area equals one square foot, and velocity equals one foot per second). Under these conditions it is evident that K and L are equal. However, it has already been mentioned that as the angle of attack of an airfoil increases, the lift also increases. It is obvious, then, that as the angle of attack increases, the constant (K) must also increase. In other words, the numerical value of K depends upon the angle of attack of the airfoil as well as upon the characteristics of the particular airfoil used. In aerodynamics, the symbol C_L is substituted for K, and is called the *coefficient of lift of the airfoil.* If the K in equation (2) be replaced by C_L, the equation of lift is:

$$L = C_L \frac{\rho}{2} SV^2. \tag{4}$$

The second column in the following table gives the values of the coefficient of lift for the Clark Y airfoil for different angles of attack. These coefficients are the results of actual wind-tunnel experiments. The figures appearing in the third and fourth columns of the table will be explained in a later section.

TABLE III

LIFT AND DRAG CHARACTERISTICS OF THE CLARK *Y* AIRFOIL

Angle of attack	C_L	C_D	Approx. C_D/C_L or $\frac{L}{D}$
— 4°	0.07	0.010	
— 3	0.14	0.010	
— 2	0.215	0.012	0.0582
— 1	0.285	0.014	
0	0.36	0.017	0.0485
1	0.43	0.020	
2	0.50	0.024	0.0496
3	0.57	0.028	
4	0.645	0.033	0.0536
5	0.715	0.038	
6	0.785	0.045	0.0591
7	0.875	0.052	
8	0.93	0.060	0.0665
12	1.19	0.095	
16	1.435	0.139	0.097
18			0.108

(maximum safe coefficient of lift is 1.56)

Relation of lift to weight. When a plane is in equilibrium, as in straight level flight, the total lift is equal to the weight of the plane. It is obvious, then, that *W* may be substituted for *L* in the lift equation.

$$W = C_L \frac{\rho}{2} S V^2. \tag{5}$$

If this equation be solved for the velocity, the resulting equation may be used to determine the velocity necessary to support a given load with a certain particular airfoil at a constant angle of attack.

$$V^2 = \frac{W}{C_L \frac{\rho}{2} S} \qquad \text{or}$$

$$V = \sqrt{\frac{W}{C_L \frac{\rho}{2} S}} = \sqrt{\frac{2W}{C_L \rho S}}. \tag{6}$$

In equations (5) and (6), if W represents the weight of the plane in pounds, C_L the coefficient of lift, ρ the air density in slugs per cubic foot, and S the surface area of the wing in square feet, the velocity determined by computation will be in feet per second. If L be substituted for W in equation (6), then the velocity required to provide a certain lift may be determined. This equation is important in determining the velocity necessary for the take-off of an airplane if its weight, wing area, and wing characteristics, at a given altitude and angle of attack, are known. It should be pointed out here that there is not a definite angle of attack or a definite speed for take-off, since there is a considerable range available. For example, what velocity is required for the take-off at 4000 feet altitude of a 2000-pound airplane whose wing area is 500 square feet, assuming the angle of attack to be 1°?

$$V = \sqrt{\frac{2 \times 2000}{.43 \times .002112 \times 500}} = \sqrt{8889} = 95 \text{ ft./sec. approx.}$$

$$\text{Airspeed} = 95 \times .682 = 65 \text{ m.p.h. approx.}$$

Condition for minimum flying speed. It is apparent from equation (6) that in order to fly at the slowest possible speed at a given altitude, only one factor can change. The factors W and S remain constant for the plane, and ρ remains relatively constant for any given altitude. It is clear, then, that C_L determines the minimum flying speed. As C_L decreases, V must increase, and as C_L increases, V decreases. Thus the minimum speed will be attained when the C_L is maximum.

$$\text{Min. } V = \sqrt{\frac{2W}{\text{Max. } C_L \rho S}}. \qquad (7)$$

A plane usually lands at its minimum speed in order that the ground run may be as short as possible.

Exercise 39. What is the lift on a Clark Y wing 300 sq. ft. in area at 6° angle of attack and airspeed of 90 m.p.h.? Assume sea-level air density.

Exercise 40. A monoplane weighs 4400 pounds and has a Clark Y wing 350 sq. ft. in area. What should the angle of attack be at an airspeed of 100 m.p.h.? Assume sea-level air density.

Exercise 41. What is the landing speed at sea level of an airplane weighing 4000 pounds, with a Clark Y wing 350 sq. ft. in area?

Exercise 42. An airplane has a Clark Y wing 450 sq. ft. in area.

What is the greatest weight this airplane can have if the landing speed does not exceed 40 m.p.h. at sea level? [Hint: Square both sides of equation (7).]

Exercise 43. An airplane weighing 6000 pounds has a Clark *Y* wing 675 sq. ft. in area. What is its minimum speed at sea level and at 15,000 feet?

Exercise 44. An airplane weighing 5000 pounds has a wing area of 240 sq. ft. and a landing speed of 55 m.p.h. What is the landing speed in miles per hour with 500 lbs. more load and 60 sq. ft. less wing area?

Factors that influence drag. The factors that influence the lift of an airfoil also influence the drag. The larger the wings, the greater the surface exposed to air resistance; also the faster the wing moves, the greater the resistance. Likewise, as the air becomes more dense, it offers greater resistance. By substituting D for L and C_D for C_L in the lift equation, the drag equation is obtained.

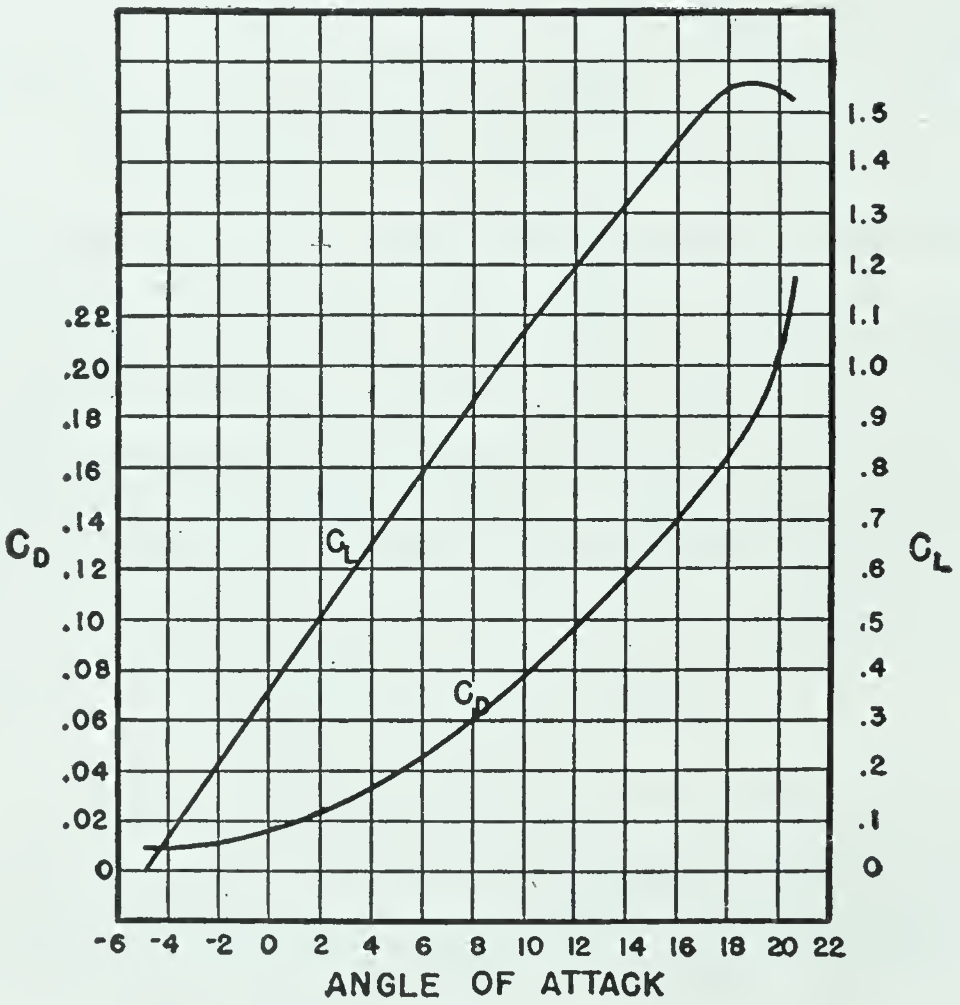


Fig. 107. Characteristic curves of Clark Y airfoil

$$D_{\text{Wing}} = C_D \frac{\rho}{2} S V^2. \qquad (8)$$

Table III gives values of both lift and drag coefficients and the ratio of drag to lift for the Clark *Y* airfoil, and Figure 107 shows graphically the relationship between the two. Similarly, Figure 108 shows the relationship between lift and drag for a Göttingen 398 airfoil. It is apparent from the graph that the drag increases slowly at low angles of attack, but increases rapidly at high angles of attack. When the angle of attack approaches 19°, the lift decreases, the drag increases greatly, and the burble point is reached. This is the angle of attack at which the plane stalls. If a plane stalls, it loses its flying speed and does not respond to changes in the wing-control surfaces (ailerons), and responds very reluctantly to the tail-control surfaces (rudder and elevator).

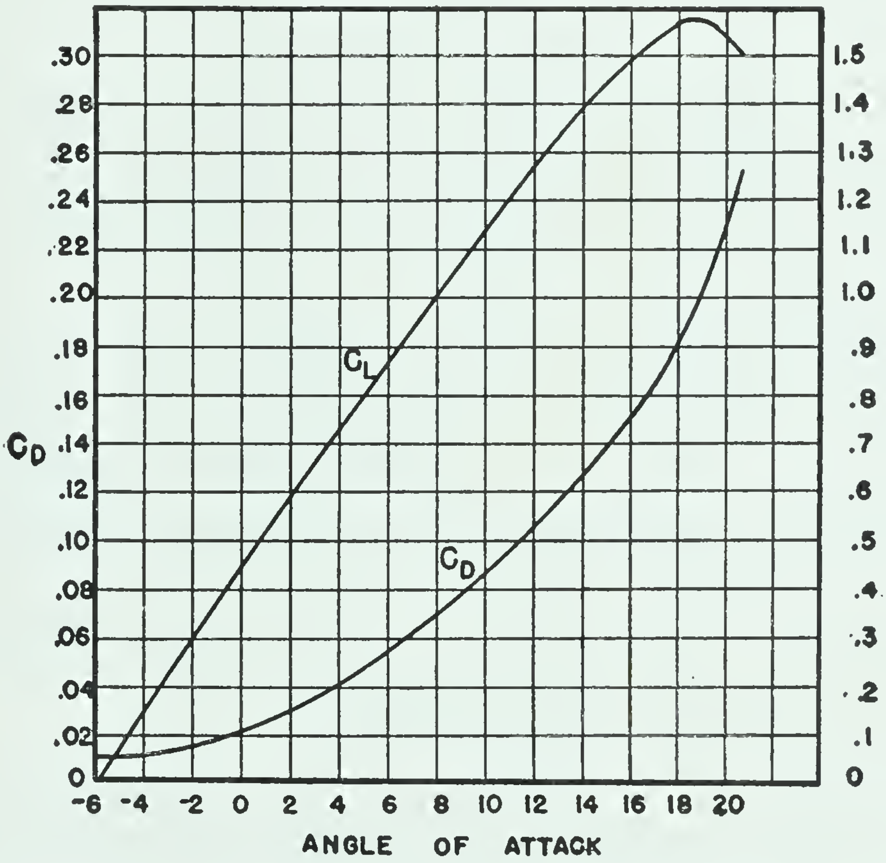


Fig. 108. Characteristic curves of Göttingen 398 airfoil

It was mentioned earlier in this unit that the total drag of an airplane is equal to the sum of wing drag and parasitic drag. The resistance to motion offered by the parasite of a plane is considered as if the parasite were a flat plate (see Fig. 83) that offers the same resistance. If the equivalent flat-plate area is represented by *a,* then the equation for parasitic drag may be written:

$$D_{\text{Par.}} = 1.28 \frac{\rho}{2} a V^2 . \tag{9}$$

It is evident, then, that the total drag of the airplane is:

$$D_{\text{total}} = \underbrace{\left(C_D \frac{\rho}{2} SV^2\right)}_{\text{wing}} + \underbrace{\left(1.28 \frac{\rho}{2} aV^2\right)}_{\text{parasitic}}. \tag{10}$$

Relation of thrust to drag. As previously stated, if an airplane is in equilibrium, the thrust is just equal to the total drag. In other words, the thrust necessary to overcome wing drag is:

$$T_{\text{Wing}} = C_D \frac{\rho}{2} SV^2 \tag{11}$$

and the thrust necessary to overcome parasitic drag is:

$$T_{\text{Par.}} = 1.28 \frac{\rho}{2} aV^2. \tag{12}$$

If now T_t be substituted for D_t in equation (10), the result will be the equation for the total thrust necessary to fly a plane.

Exercise 45. What is meant by the terms *coefficient of lift* and *coefficient of drag?*

Exercise 46. What is the drag at 8000 feet altitude of a Clark *Y* wing 200 sq. ft. in area flying at 110 m.p.h. and at a 3° angle of attack?

Exercise 47. What is the parasite drag at 10,000 feet altitude of a plane flying at 300 m.p.h. if the equivalent flat-plate area is 2 sq. ft.?

Exercise 48. What is the total drag on the airplane described in problem 1 if the equivalent flat-plate area is 1.5 sq. ft.? What is the total thrust if the plane is in equilibrium?

Exercise 49. If the thrust necessary to overcome parasite drag of a plane is 200 pounds at 100 m.p.h. at sea level, what is the equivalent flat-plate area of the parasite?

Exercise 50. Prepare a table (as in Table III) showing the coefficients of lift and drag for angles of attack ranging from —4° to 18°. Work from Figure 108.

Problem 5. What factors determine the power required of an airplane engine?

Relation between velocity, thrust, and power. The power of an engine depends upon the amount of work it can do in a given length of time. In an earlier section of this unit, work was defined as the product of force and the distance through which the force moves or:

Work = F × S. A machine is said to be working at the rate of one horsepower when it does 550 foot pounds of work each second. Horsepower may, therefore, be determined from the equation:

$$H.P. = \frac{F \times S}{550 \times T}$$

in which F is in pounds, S is in feet, and T is in seconds. The same equation may be rewritten in a slightly different form without changing its value.

$$H.P. = \frac{1}{550} \times F \times \frac{S}{T}.$$

In this equation $\frac{S}{T}$ (distance divided by time) is the ratio used to determine average *velocity*. In other words, *horsepower is proportional to the product of force and velocity*. If force is measured in pounds, and velocity in feet per second, the constant of proportionality is $\frac{1}{550}$. For example, if it takes 500 pounds of force to move an object with a constant velocity of 11 feet per second, the horsepower used is $\frac{1}{550} \times 500 \times 11$, or ten horsepower.

In the case of the airplane, the force effective in moving the plane is the *thrust* (T). The horsepower required for flight at uniform speed, therefore, is:

$$H.P. = \frac{TV}{550}. \tag{13}$$

Relation of power to weight. The following relationships applicable to an airfoil have already been established.

$$\text{Thrust} = \text{drag} = C_D \frac{\rho}{2} SV^2.$$

$$\text{Weight} = \text{lift} = C_L \frac{\rho}{2} SV^2.$$

Therefore,

$$\frac{\text{Thrust}}{\text{Weight}} = \frac{\text{drag}}{\text{lift}} = \frac{C_D}{C_L} \text{—or}$$

$$T = \left(\frac{C_D}{C_L} \times W\right) = \left(\frac{D}{L} \times W\right).$$

This may also be written: $T = \frac{W}{(L/D)}$.

It is apparent then that if this value for T be substituted in equation (13) a relationship will be obtained between power and weight.

$$H.P. = \frac{\left(\frac{D}{L} \times W\right) V}{550} \quad \text{—or} \tag{14}$$

$$H.P. = \frac{WV}{(L/D)\,550}.$$

Total horsepower required. The total horsepower required by an airplane flying at uniform speed depends on the thrust necessary, which in turn depends on the total drag.

Equation (13) may be rewritten in two forms, one to indicate the horsepower necessary to overcome wing drag:

$$H.P._{\text{wing}} = \frac{T_w V}{550} = \frac{\left(C_D \frac{\rho}{2} S V^2\right) V}{550} \tag{15}$$

and the other to indicate the horsepower necessary to overcome parasitic drag.

$$H.P._{\text{par.}} = \frac{T_p V}{550} = \frac{\left(1.28 \frac{\rho}{2} a V^2\right) V}{550}. \tag{16}$$

The total horsepower required is obtained by combining equations (15) and (16):

$$H.P._{\text{total}} = H.P._{\text{wing}} + H.P._{\text{par.}} \quad \text{—or}$$

$$H.P._{\text{total}} = \frac{C_D \frac{\rho}{2} S V^3 + 1.28 \frac{\rho}{2} a V^3.}{550} \tag{17}$$

As an example of the use of this relationship, we may consider the following problem: What is the total horsepower necessary to fly (in a level flight condition) a plane with a Clark Y wing of 330 square feet area at a velocity of 100 feet per second? Assume the plane to have an equivalent flat-plate area of 2.2 square feet and to be flying at 3000 feet altitude at a 4° angle of attack.

$$\text{H. P.}_{\text{total}} = \frac{(.033 \times .001088 \times 330 \times 1{,}000{,}000) + (1.28 \times .001088 \times 2.2 \times 1{,}000{,}000)}{550}$$

$$= 1088 \frac{(.033 \times 330 + 1.28 \times 2.2)}{550} = 27.1 \text{ approximately}$$

Effect of changing density on speed and power. The drag of a wing for constant lift is the same for a given angle of attack for all altitudes, since the increase in velocity necessary to produce the required lift at higher altitudes counteracts the effect of a decrease in air density. However, since the power required is the product of drag and velocity (or thrust and velocity), and since the maintenance of lift at higher altitudes requires greater velocity, it follows that more power must be used.

The lift necessary to support a plane of given weight in air of different densities remains constant and is in each case equal to the weight of the plane.

$$\text{Weight} = L = C_L \frac{\rho_0}{2} S V_o^2 = C_L \frac{\rho_a}{2} S V_a^2.$$

Therefore, if both the angle of attack and the wing area remain constant:

$$\rho_0 V_o^2 = \rho_a V_a^2$$

and:

$$V_a^2 = \frac{\rho_0}{\rho_a} V_o^2 \quad \text{—or}$$

$$V_a = V_0 \sqrt{\frac{\rho_0}{\rho_a}} \tag{18}$$

in which ρ_0 is the air density at the altitude where velocity V_0 is necessary to sustain the plane and ρ_a is the air density at the altitude where a greater velocity V_a is necessary. This equation enables one to calculate the velocity necessary for a plane to take off at different altitudes provided the same angle of attack is used. It should be understood, however, that high-altitude take-offs are usually made at a lower angle of attack in order to provide a greater margin of safety above the increased stalling speed.

Similarly, if $H.P._0$ is the horsepower required at sea level and $H.P._a$ is the horsepower required at the altitude where the density is ρ_a, then;

$$H.P._0 = \frac{DV_0}{550}$$

and:

$$H.P._a = \frac{DV_a}{550}.$$

Substituting the value for V_a (equation 18), then:

$$H.P._a = \frac{DV_0\sqrt{\frac{\rho_0}{\rho_a}}}{550}$$

and, therefore:

$$H.P._a = H.P._0\sqrt{\frac{\rho_0}{\rho_a}}. \tag{19}$$

This equation is important in determining the power necessary for a given plane to take off at different altitudes. For example, if it requires 200 *H.P.* for a plane to take off at sea level, how much power will be required by the same plane to take off at 5000 feet altitude using the same angle of attack?

Solution: $H.P._0 = 200$; $\rho_0 = .002378$; $\rho_a = .002049$.

$$H.P._a = 200\sqrt{\frac{.002378}{.002049}} = 200\sqrt{1.11} = 210.8.$$

Effect of changing weight on velocity and power. If wing area and density are constant, for the same angle of attack (*i.e.*, C_L and C_D remain constant), the power required for the wing varies as the cube of the square root of the weight. This relationship may be expressed by the equation:

$$\frac{H.P._2}{H.P._1} = \left(\frac{W_2}{W_1}\right)^{\frac{3}{2}} \text{—or}$$

$$H.P._2 = \frac{W_2}{W_1} \times \sqrt{\frac{W_2}{W_1}} \times H.P._1 \tag{20}$$

In this equation $H.P._1$ is the horsepower necessary when the weight is W_1 (original weight) and $H.P._2$ is the horsepower necessary when the weight is changed to W_2, all other factors being equal.

On the other hand, as the weight of a plane increases, the velocity necessary to sustain that weight without changing the angle of attack must necessarily increase. Thus,

$$V_2 = V_1 \sqrt{\frac{W_2}{W_1}} \tag{21}$$

where V_1 is the original velocity corresponding to weight W_1, and V_2 is the new velocity required for weight W_2.

Effect of changing wing area on velocity and power. If all other factors are equal, the following formula may be used to find the effect of a change in wing area on velocity:

$$V_2 = V_1 \sqrt{\frac{S_1}{S_2}} \tag{22}$$

where V_1 represents the original velocity corresponding to wing area S_1, and V_2 represents the new velocity corresponding to the changed wing area S_2.

Similarly, equation (23) may be used to determine the effect of a change in wing area on horsepower.

$$H.P._2 = H.P._1 \sqrt{\frac{S_1}{S_2}}. \tag{23}$$

For example, if it requires 200 horsepower to sustain a plane of 300 square feet wing area, how much power is required if the wing area is doubled, all other factors being equal?

$$H.P._1 = 200;\ S_1 = 300;\ S_2 = 600.$$

$$H.P._2 = 200 \sqrt{\frac{300}{600}} = 200 \sqrt{\frac{1}{2}}.$$

$$H.P._2 = 141.4 \text{ approximately.}$$

Exercise 51. If it requires a thrust of 1000 pounds to move a plane through the air at 80 miles per hour, what horsepower is used?

Exercise 52. What horsepower is required to move a Clark *Y* wing 100 m.p.h. at a 10° angle of attack? The weight of the plane is two tons.

Exercise 53. What horsepower is necessary to overcome the wing drag of a plane with a Clark *Y* wing at a 6° angle of attack at 120 feet per second? The wing area is 500 square feet, and the plane is flying at 6000 feet altitude.

Exercise 54. What horsepower is necessary to overcome the parasitic drag of the plane in problem 53 if its equivalent flat-plate area is 3 square feet?

Exercise 55. What would be the total drag of the plane in problems 53 and. 54 if it were flying at 15,000 feet at 300 feet per second and at the same angle of attack? What horsepower is required?

Exercise 56. The velocity of a plane at sea level is 132 feet per second and is just sufficient to support the plane. What velocity will be necessary to support the same plane at 10,000 feet altitude, all other factors being equal?

Exercise 57. If the horsepower required at sea level for problems 56 is 350 h.p., what power is required to fly the plane at 10,000 feet altitude, all other factors being equal?

Exercise 58. If it requires 2000 horsepower to fly a bomber whose total weight is 30,000 pounds, what horsepower will be required to fly the same bomber if the total weight is increased to 50,000 pounds, all other factors remaining unchanged.

Exercise 59. The airspeed necessary to fly a 1000-pound plane at sea level is 60 m.p.h. What airspeed will be required if the weight is increased 300 pounds? What airspeed will be required of the same plane under both conditions at 3000 feet altitude?

Exercise 60. The minimum velocity for take-off of a plane of 600 square feet wing area at sea level is 88 feet per second. If the wing area is doubled, what will be the minimum velocity necessary for take-off at 5000 feet altitude?

Exercise 61. The Boeing Flying Fortress takes off, weighing 45,000 pounds. Flying at a certain angle of attack, the wing requires 2000 horsepower. After it has burned 800 gallons of fuel (gasoline weighs 6 pounds per gallon), what power is required by the wing at the same angle of attack?

Exercise 62. If it requires 300 h.p. to fly a plane of given wing area, what h.p. will be required if the wing area is (a) doubled? (b) tripled? (c) cut in half?

Effect of turning on velocity and power. In straight level flight the force of gravity is the only exterior force acting on an airplane. However, in a turn, centrifugal force also acts on a plane, and the resultant of the force of gravity and centrifugal force is the exterior force acting on the plane. The weight of the plane is constant, but the centrifugal force depends on the sharpness of the turn. The resultant force acts in a downward and outward direction. Under these conditions, if the plane is not banked, it will skid.

The angle between a wing and the horizon is called the angle of bank. If a pilot is flying correctly, this angle of bank must be numerically equal to the angle between the resultant force and the vertical. (Fig. 109.) Similarly, the lift must be equal in magnitude to this resultant force. If the angle of bank is correct and the lift equals the resultant, a correct turn results.

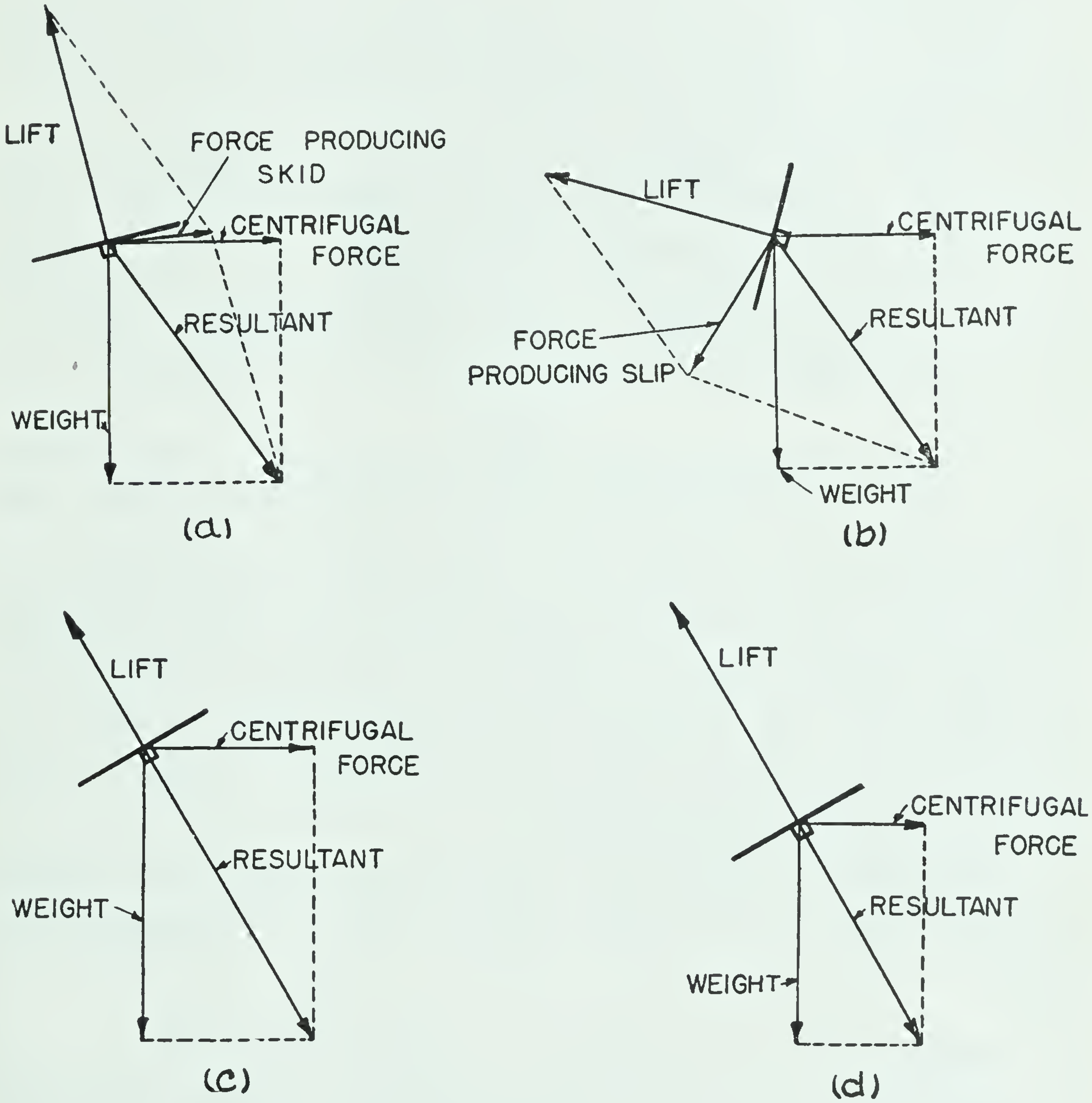


Fig. 109. Forces in a turn

Referring now to Figure 109, if the angle of bank is not enough, as in *a,* the lift will not be acting in a direction exactly opposite to the resultant. Then, if the lift is combined with the resultant, a new resultant force is produced which acts to pull the airplane outward. In other words, the airplane skids.

On the other hand, if the angle of bank is too steep (Fig. 109 *b*), the lift and the resultant of weight and centrifugal force will combine and produce a force that acts inward and downward, and the plane will slip.

The plane may be banked properly, but the lift may not be as great as the resultant (Fig. 109 *c*). As a result, the plane will squash or settle outward.

Figure 109 *d* illustrates a properly banked turn in which the lift is equal to the resultant. This results in a climbing turn in which the plane neither slips, skids, nor settles.

In turns there must be greater lift than in a straight flight. Greater lift is obtained either by flying faster, or at a greater angle of attack, or by a combination of both. At the same angle of attack but with increased airspeed, the drag increases. Also, with a greater angle of attack at the same airspeed, the drag increases. Because of the increased drag, either added power is used, or altitude is lost in a turn.

At higher altitudes, greater speed is necessary to maintain the plane in the air at unchanged angle of attack. This requires additional power. As a result, there is less available excess power at high altitudes than at sea level. Consequently, sharp snappy turns that may be made at sea level require more power than is available at higher altitudes, and the radius of the turn must, therefore, be increased. In a turn of radius r the centrifugal force is $\frac{MV^2}{r}$. As r increases, the centrifugal force decreases. Thus, less lift and less power are required for wide turns.

Exercise 63. Explain why a plane slips if a turn is not properly executed. Explain why a plane skids if a turn is not properly executed.

Problem 6. How is the stability of a plane maintained?

A pendulum, if set in motion, eventually returns to its original position; it is said to be in *stable* equilibrium. If a ball is rolled across a flat level surface and stopped, it will remain in its new position; thus, it is in *neutral* equilibrium. If a body when disturbed has a tendency to move farther from its original position, its equilibrium is said to be *unstable*.

Stability of an airplane is an inherent property that enables it to return to a state of equilibrium if that equilibrium is upset or destroyed. An airplane has three axes about which it must be stable in order to be in equilibrium. These axes are the longitudinal, lateral, and vertical axes (Fig. 110) about which the plane is subject to rolling, pitching, or yawing, respectively, much as a small steamship is tossed about in a storm. The axes of an airplane all intersect at right angles to each other at the C. G. of the plane, and usually all disturbances take place about one or more of these axes.

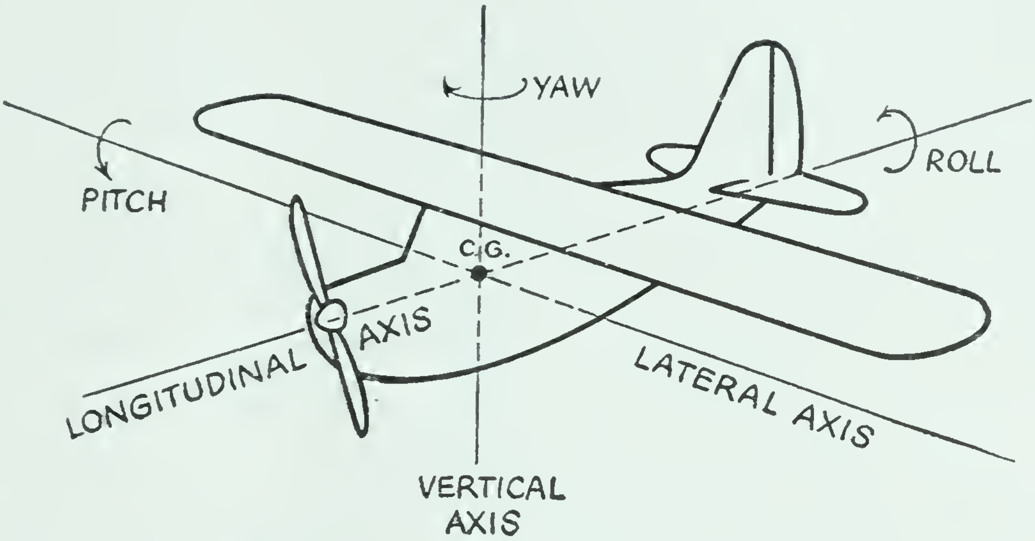


Fig. 110. The three axes of an airplane

Longitudinal stability. If a steamship is plowing through heavy seas, the prow of the ship rises and falls as it meets first a wave and then a trough of the sea. In a similar manner, the nose of an airplane may rise and fall in turbulent air. This motion is called the *pitch* of the plane. A plane pitches about its lateral axis (Fig. 111). This pitching may be caused either by accidental movement of the controls in the pilot's compartment or by changes in vertical aerodynamic forces on the horizontal lifting and control surfaces produced by either vertical motion of the air or by changes in its horizontal velocity. In either case, the ship must be righted.

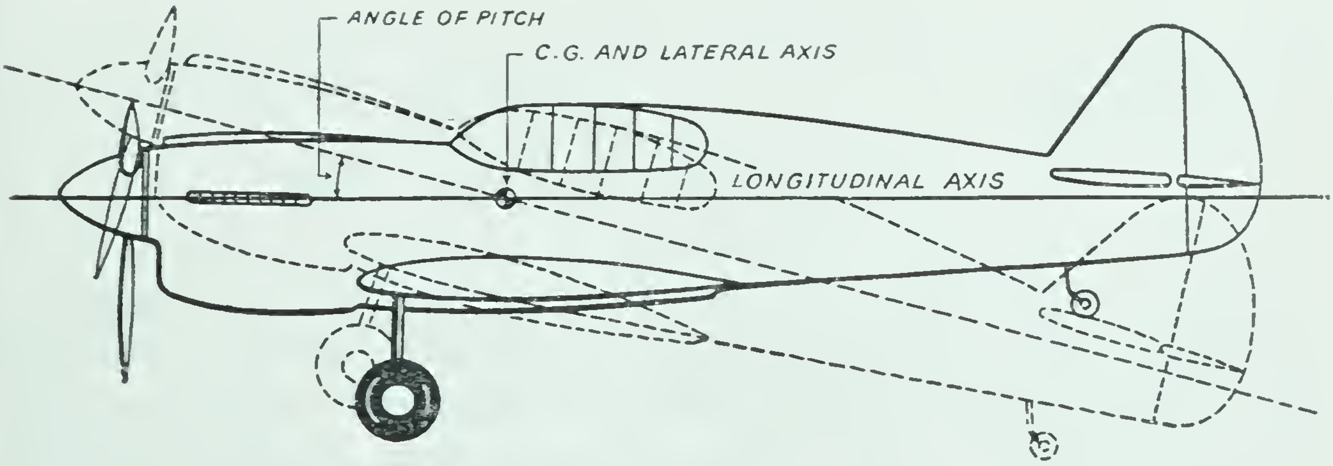


Fig. 111. Pitching of a plane about its lateral axis

One method of returning a plane to level position involves adjustment of the controls by the pilot. However, if the plane is longitudinally stable, it will return to a state of equilibrium by itself because of the air forces acting on it. It must be remembered that the C. G. in a stable airplane is located ahead of the C. P., which necessitates a downward aerodynamic force on the stabilizer to maintain equilibrium (see Fig. 104). An upward displacement of the nose of the plane, due to an upward or positive gust on the wing, increases the angle of attack, thereby *increasing drag* and *reducing speed.* After this reduction of speed has occurred (not instantly), the downward force on the stabilizer decreases and allows the tail to rise. Since it is unlikely that normal speed will be regained by the time the longitudinal axis has returned to horizontal, the tail will continue to rise, thus putting the plane into a shallow dive. It cannot by itself recover from this dive until *speed has increased,* which in turn increases the downward tail load and pushes the tail downward. These oscillations of the plane should decrease in amplitude, and the ship should return to level flight after two or three oscillations, depending, of course, on their original amplitude. If the plane continues to oscillate, it has *static* stability, but if it returns to level flight in the manner described above, it has *dynamic* as well as static stability. Figure 112 illustrates the difference between static and dynamic stability.

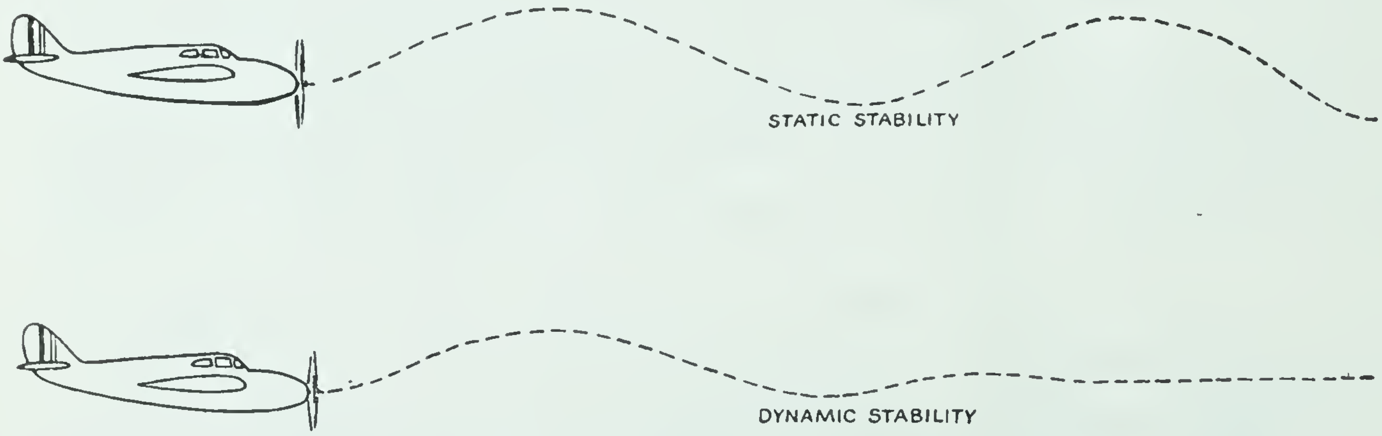


Fig. 112. Static and dynamic longitudinal stability

Directional stability. A wind vane, turning on a vertical shaft, resembles a plane pivoting on its vertical axis. If gusts of wind strike the plane and cause the tail to swing either to right or left, the plane *yaws* (Fig. 113). This yawing, if not corrected, changes the direction of travel of the airplane and throws it off its course.

As with longitudinal stability, there are control surfaces that tend to correct the yaw of a plane. These are upright tail-surfaces, *fin* and *rudder*. As the tail swings to the right in a yaw, the angle of attack of the fin increases, and the tail is forced back to its original position by the positive pressure of the airstream. The fuselage of the plane also provides a restoring force, since the positive pressure on the side exposed to the airstream is greater than the pressure on the opposite side.

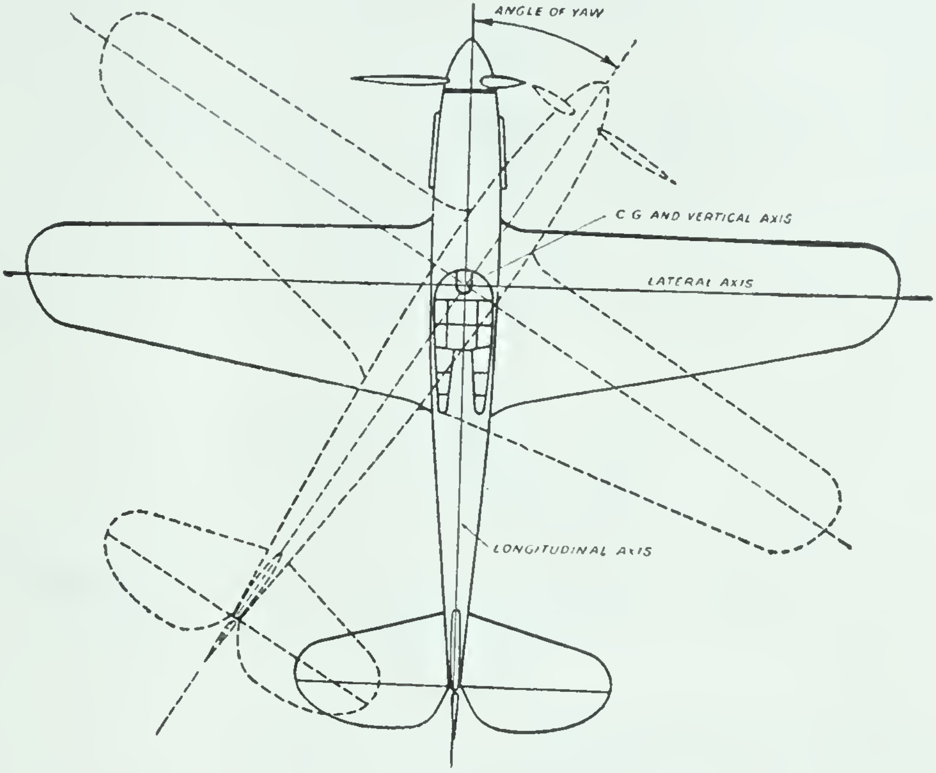


Fig. 113. Yawing of a plane

One disturbing force that interferes with directional stability of a single-motored plane is the torque component (drag) of the resultant aerodynamic action of the propeller (Fig. 101). This torque causes the plane to roll in a direction opposite to the direction of rotation of the propeller (Fig. 114). To counteract this torque, designers increase the camber of the left wing tip (if the direction of rotation of the propeller is clockwise as viewed from the pilot's compartment). This increase provides greater lift on the left wing. However, this increased lift causes additional drag of the left wing, and the plane tends to yaw to the left, as indicated by the arrow in Figure 114. This yaw is different from the yaw previously described, because the force is constantly applied instead of being applied for only a short time. The yawing movement of the left wing is compensated for by offsetting the leading edge of the vertical fin to the left.

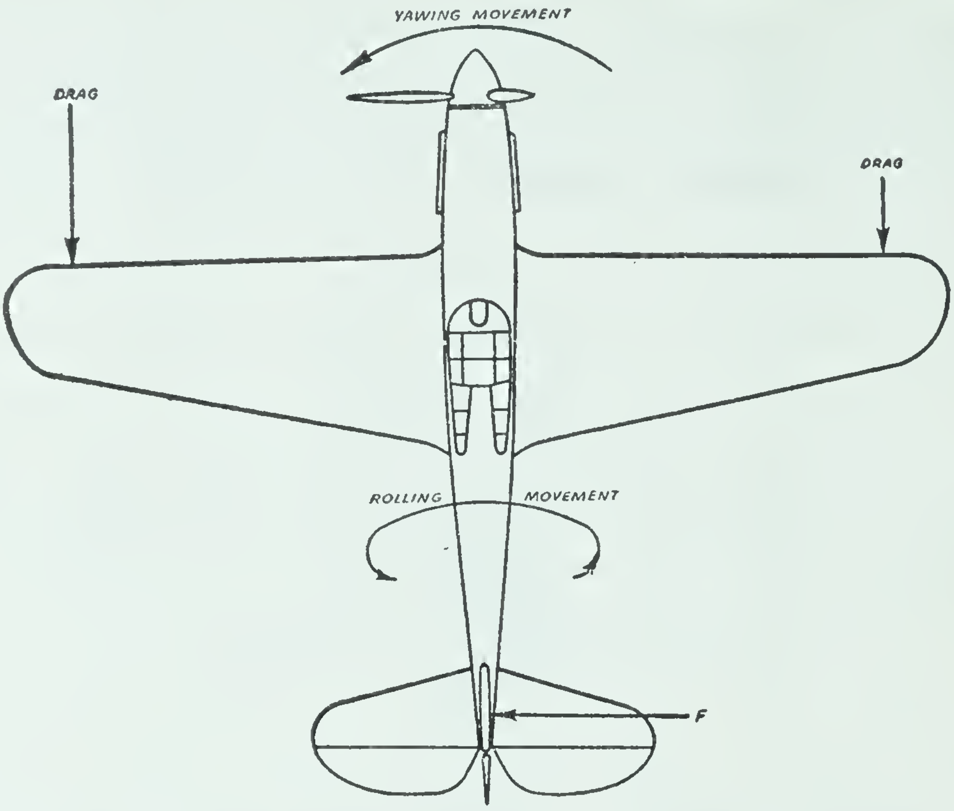


Fig. 114. Complications caused by the torque component of the propeller

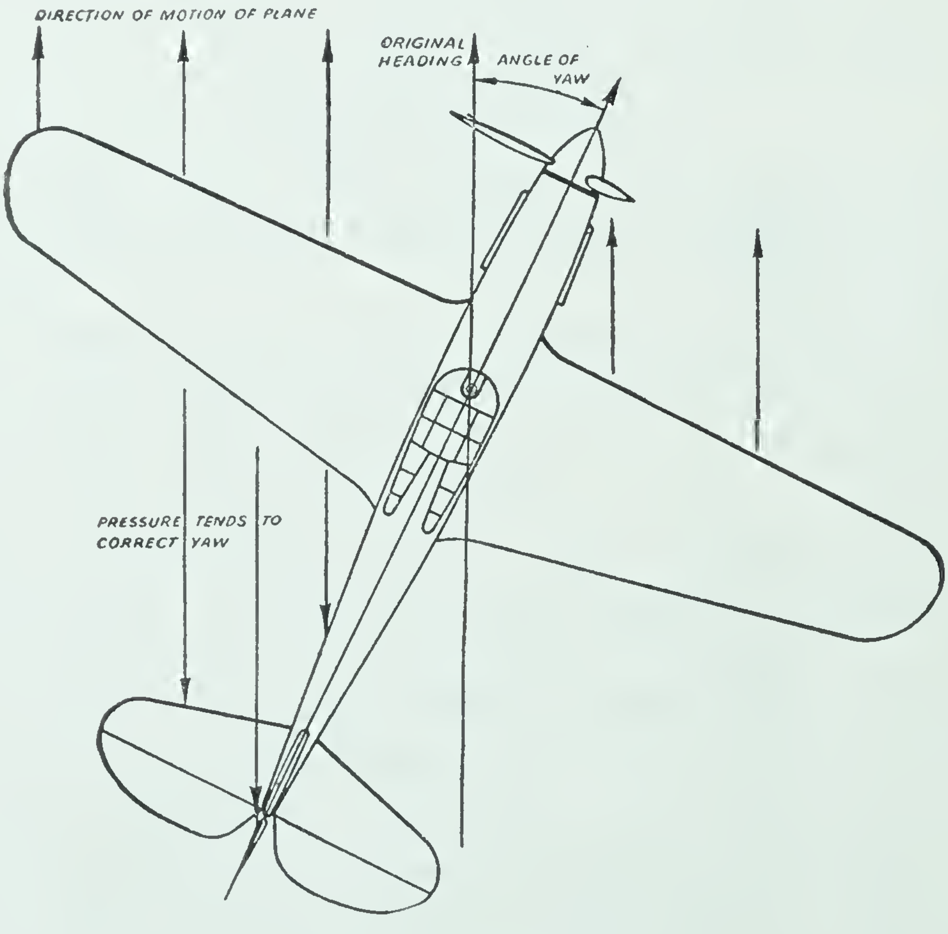


Fig. 115. Skidding

Since the effect of this offset fin varies with the speed of the ship and with the different propeller wash in cruising, climbs, or glides, this constant compensation does not provide for all conditions. Hence *rudder tabs* (to be discussed later) are used to provide fine adjustment, but are found only on heavier and more powerful aircraft.

If a plane returns to its original heading after a yaw, it has directional stability. However, the restoring tendency of the tail and other lateral surfaces of the plane are in operation only while the plane is skidding (Fig. 115). After the skidding stops, the plane will have returned very nearly (if not entirely) to its original heading. If it does not return completely, rudder action must be used. The airplane, however, will undergo a slight sidewise displacement during a skid.

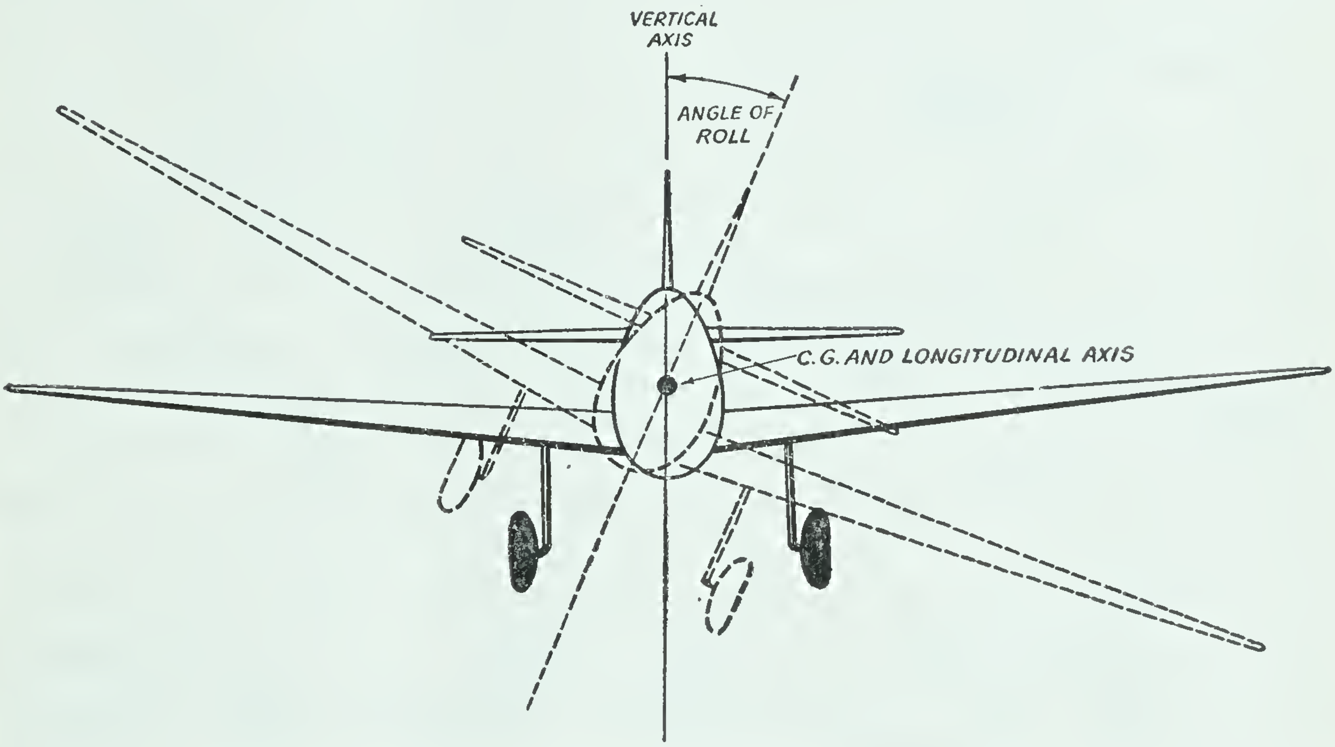


Fig. 116. Roll of a plane about its longitudinal axis

Lateral stability. A plane rolls about its longitudinal axis, much as a boat rocks from side to side (Fig. 116). If the plane returns to its original position after rolling, it has lateral stability.

Whenever a plane rolls, it sideslips. This in turn increases the angle of attack of the lower wing and increases its lift. The increased lift results in a restoring tendency that counteracts the roll. This restoring tendency is greatly increased if the wings are set at an angle to the horizon, called the *dihedral* angle (Fig. 117). As one wing tips down, the angle of attack of that wing increases; whereas the angle of attack of the other wing decreases. Thus the plane is righted by the increased lift of the lower wing. Although dihedral helps to prevent sideslipping and skidding, it also is responsible for rough, unsteady flight in turbulent air. The plane has a tendency to roll slightly with each puff of wind.

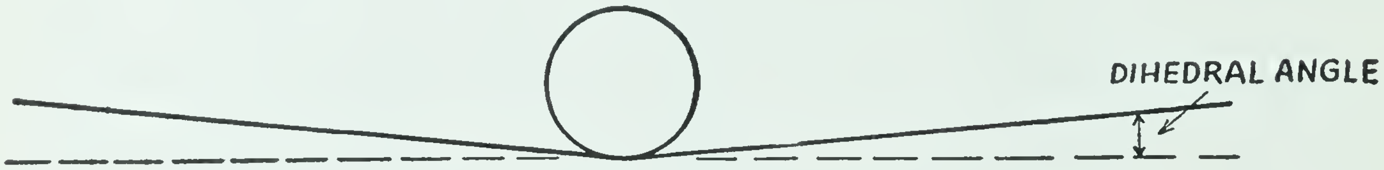


Fig. 117. Dihedral in an airplane wing

Wing control surfaces (ailerons). The wings of a plane have control surfaces located on the trailing edge near the wing tips. These surfaces are called ailerons and are operated by a sidewise motion of the control stick, or by rotation of the control wheel. As the stick is moved to the right, the right aileron turns upward and the left aileron turns downward. This change in the angle of the ailerons changes the camber (curvature) of the wings. As a result, the left wing has a greater curvature and consequently more lift and drag, which tends to raise and slow down the left wing. On the other hand, the right wing has a decreased curvature, therefore providing less lift and less drag. This decreased curvature results in a dropping and speeding up of the right wing. These two actions result in a roll in a clockwise direction. However, the increased drag of the left wing tends to produce a yaw to the left that opposes the roll. Furthermore, the increased velocity of the right wing increases its lift and, thereby, opposes the roll. When the stick is moved to the left, the opposite action occurs. Figure 118 illustrates how the camber of a wing may be changed by the aileron.

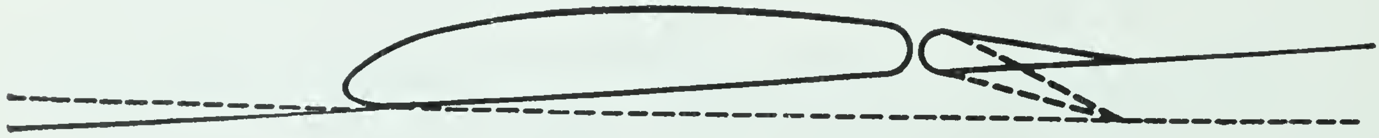


Fig. 118. Change of camber of wing by aileron

Figure 119 illustrates the different ways by which the ailerons may be controlled. In diagram *A,* a lateral motion of the stick manipulates a cable which, through a system of pulleys, causes one aileron to rise and the other to lower. As the tension on the cable increases at *b,* it is relieved at *a.* Diagram *B* shows a wheel system in which tension of the cable is controlled by a revolving drum. Diagram *C* shows still another wheel control that utilizes a system of gears instead of a drum. This arrangement is used on large planes. The diagram at *D* illustrates another control system that is used very extensively on small airplanes, and is called a torque-tube system. The arrows indicate the action of the ailerons.

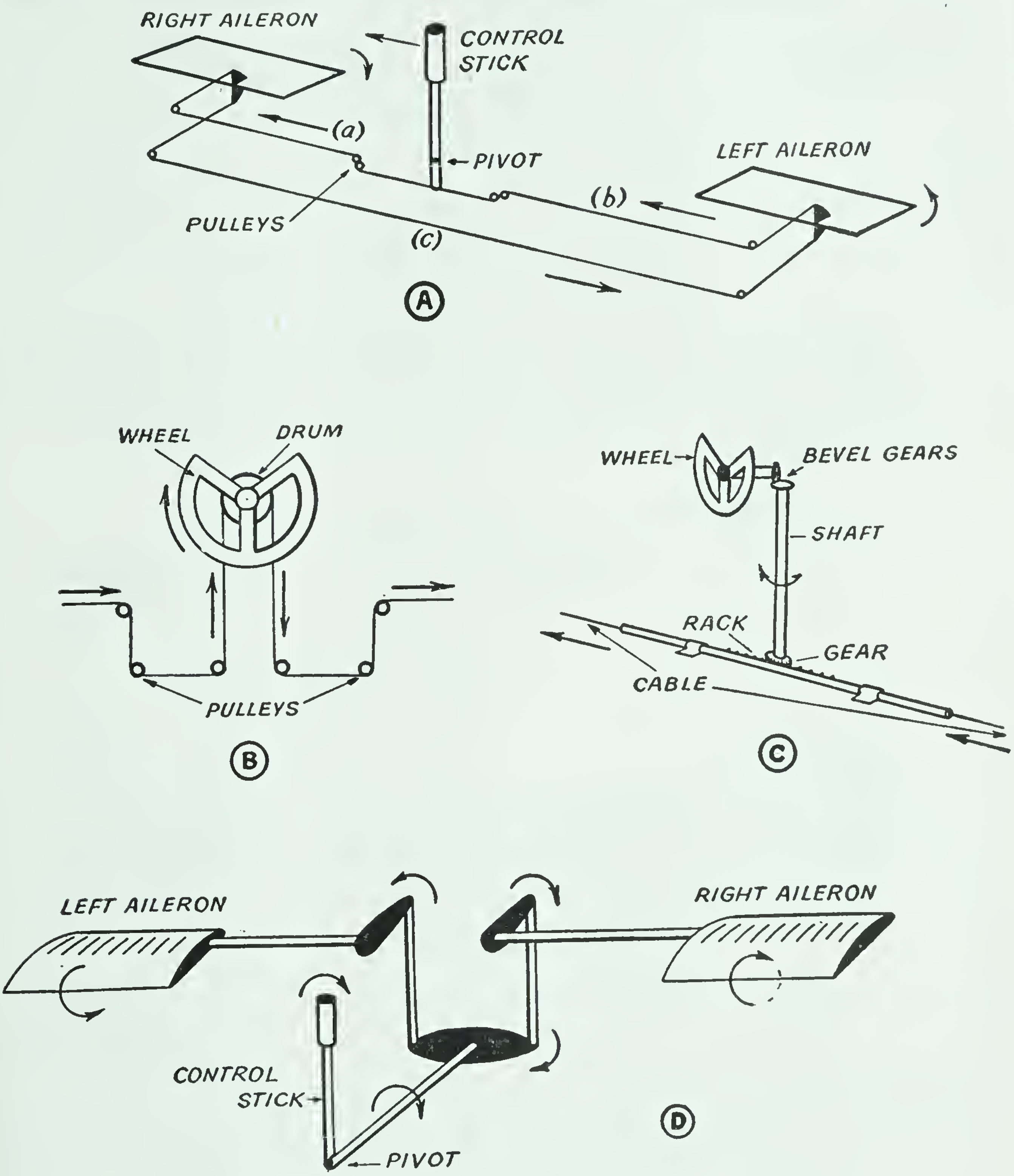


Fig. 119. Aileron control systems

Contrary to common belief, the ailerons are not raised or lowered to any great extent in a bank maneuver. In fact, the movement of the ailerons is so slight in some instances that it can scarcely be detected by observers in the plane. Moreover, once the airplane is in the desired bank, the stick and rudder must be reversed to overcome the rolling tendency of the plane. Once the rolling motion is stopped, the controls are returned to a neutral position, and the bank continues *without* the constant application of side pressure on the stick. In other words, if an airplane has stable equilibrium, it will fly in a circle with the controls in neutral, once it is started on its circular path and provided the throttle setting of the engine is correct. However, as the angle of bank is increased, an increasing back pressure must be exerted on the stick to hold the increased angle of attack necessary to provide the increased lift.

The elevator. The movable horizontal tail surface is called the elevator and is similar to an aileron in its aerodynamic effects. As the elevator is turned up (by pulling the stick back), the change in angle of attack of the tail and the subsequent increase in load cause it to drop. This drop increases the angle of attack of the airplane (*A* in Fig. 120). On the other hand, if the elevator is lowered (by pushing the stick forward), the tail rises, and the plane goes into a dive or glide (*C* in Fig. 120).

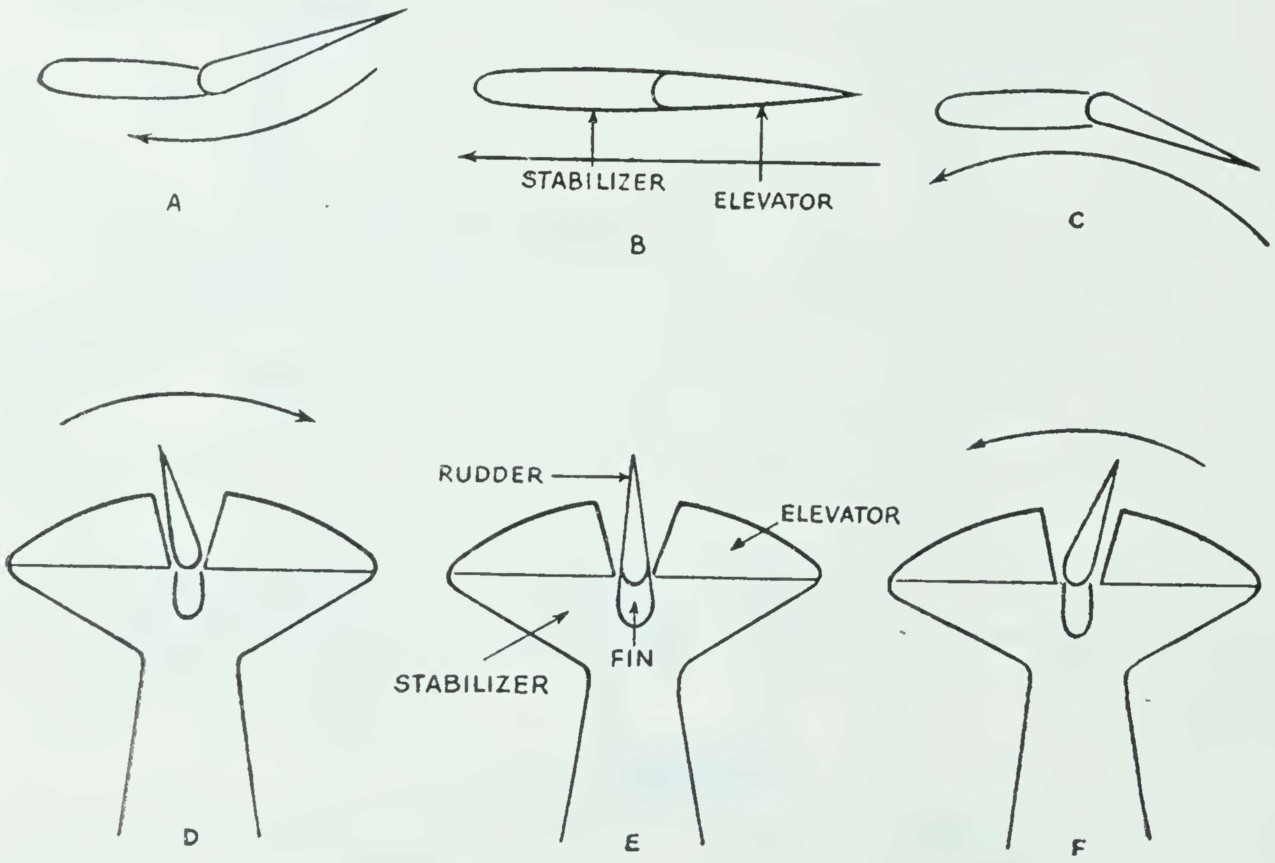


Fig. 120. Aerodynamic action of tail control surfaces

Figure 121 illustrates three different arrangements for controlling

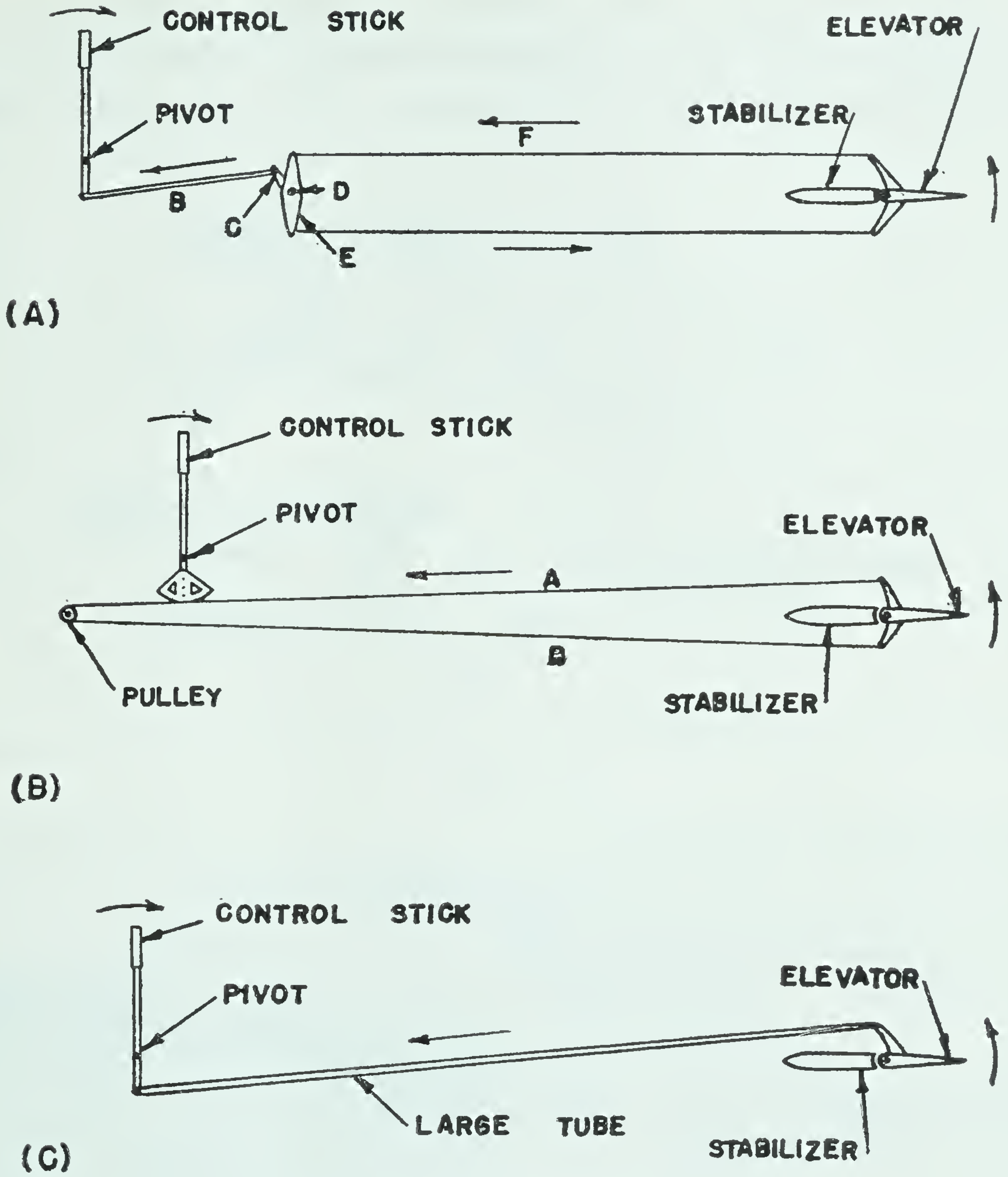


Fig. 121. Elevator control systems

the elevator. The arrows indicate, in each case, the direction of motion of stick, cables, and elevator.

The rudder. The rudder is the vertical tail surface that provides control about the yawing axis (vertical axis) of the plane. In

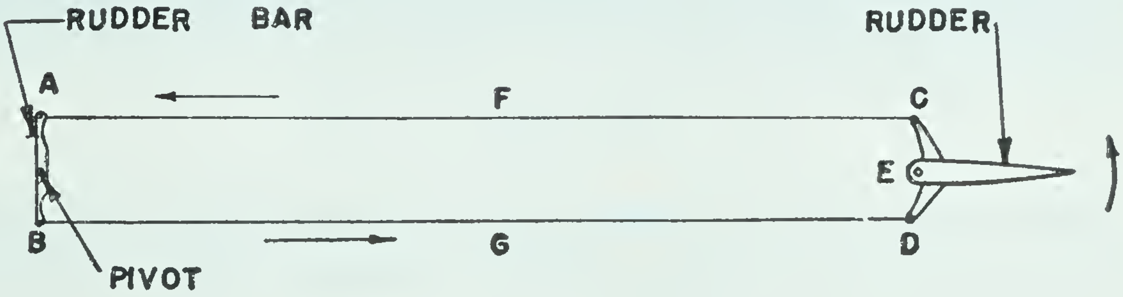


Fig. 122. A rudder control system

Figure 120, the rudder setting shown in diagram *D* produces a yaw in a clockwise direction, and that shown at *F* causes a yaw in a counterclockwise direction. This action is comparable to the rudder action of a boat and is accomplished in the airplane by applying pressure to the left or to the right end of the rudder bar (or foot pedals) as shown in Figure 122.

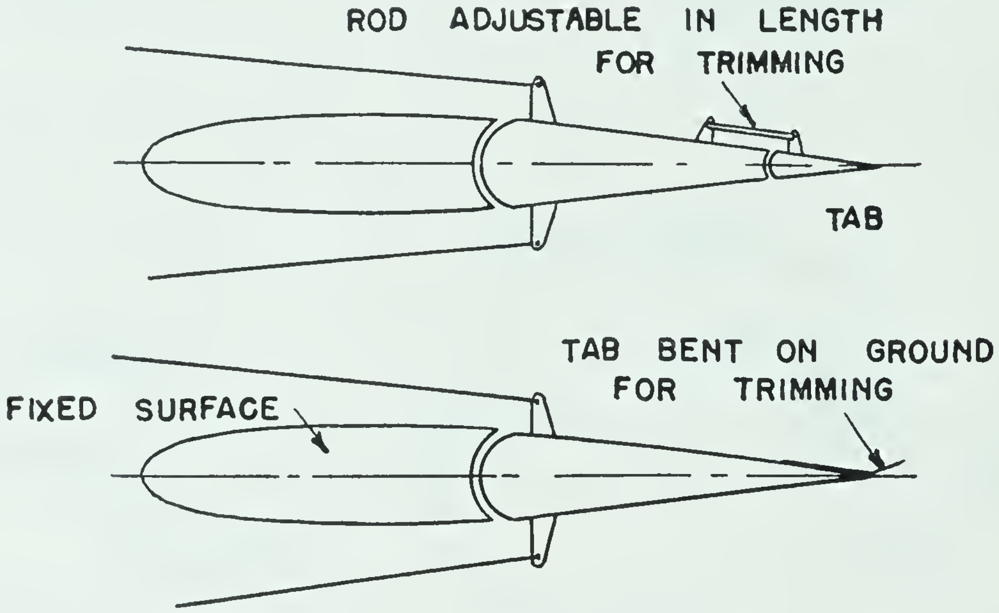

ROD ADJUSTABLE IN LENGTH FOR TRIMMING
TAB
TAB BENT ON GROUND FOR TRIMMING
FIXED SURFACE

Fig. 123 *a*

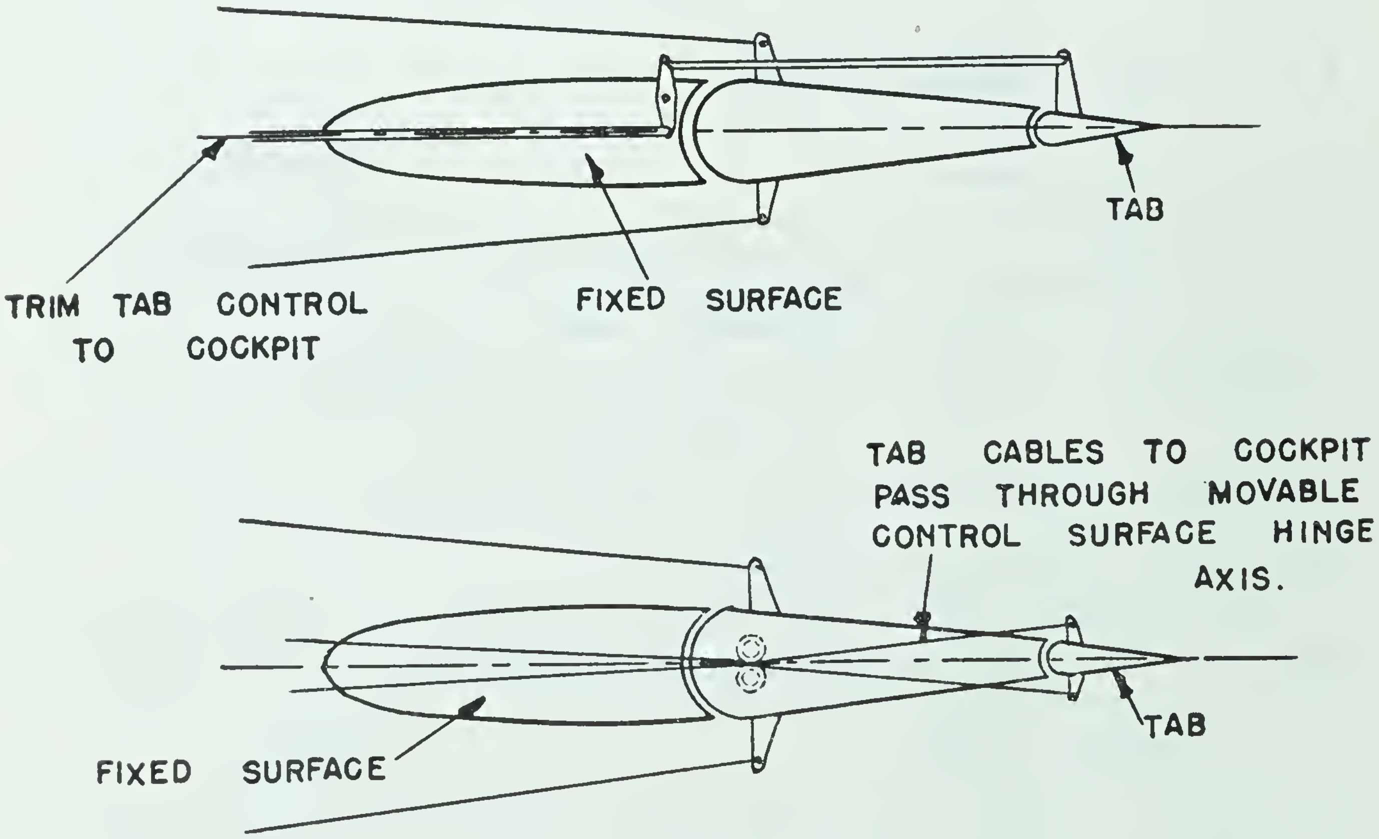
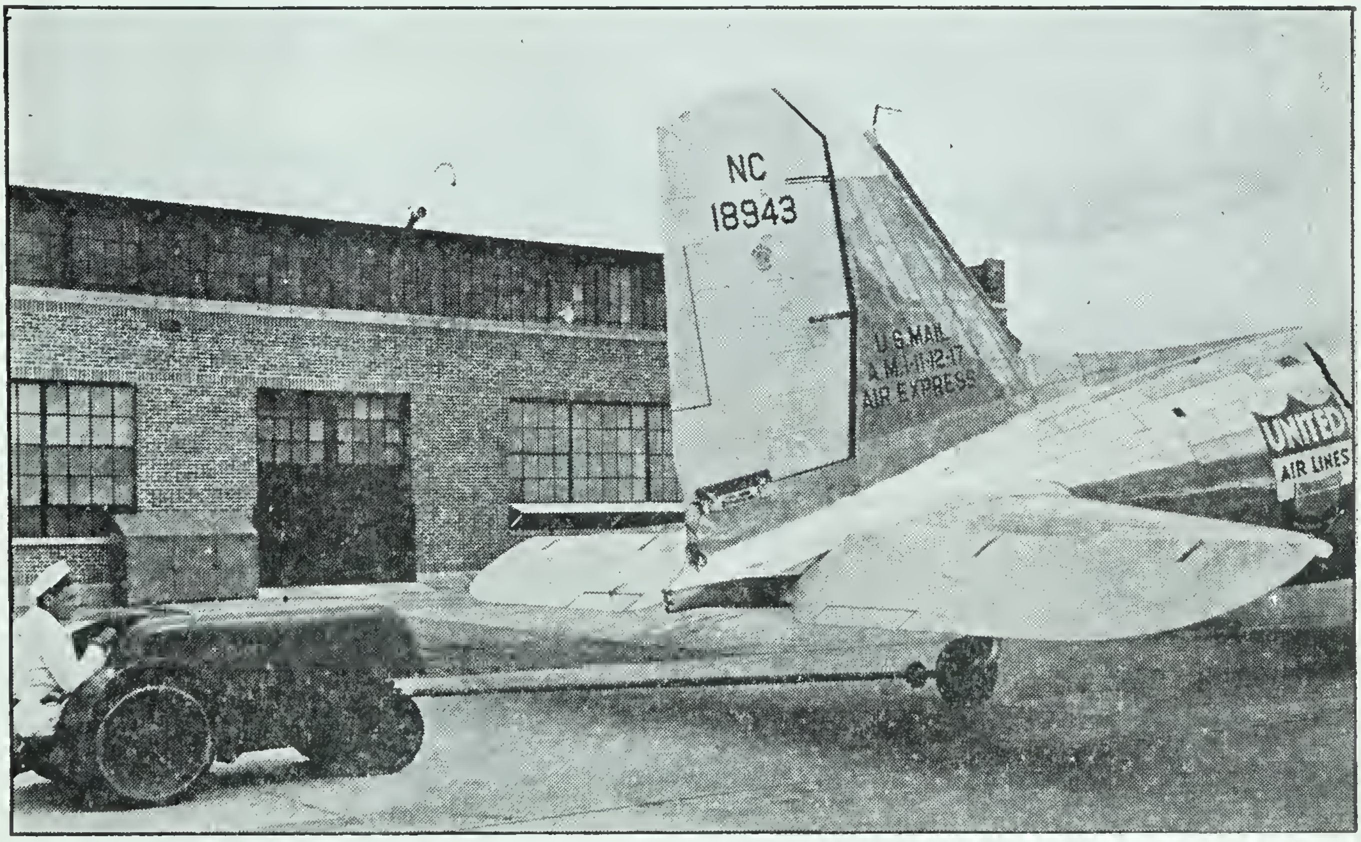

TAB
TRIM TAB CONTROL TO COCKPIT
FIXED SURFACE
TAB CABLES TO COCKPIT PASS THROUGH MOVABLE CONTROL SURFACE HINGE AXIS.
TAB
FIXED SURFACE

Fig. 123 *b*

Auxiliary control surfaces. To relieve the pilot of the necessity for constant manipulation of controls in order to maintain balance in an unbalanced airplane (unbalanced because of accident, loading, engine torque, etc.), certain auxiliary control surfaces may be installed. Fundamentally, variations in speed, loading, propeller thrust, and air density make it impossible for a plane to balance horizontally under all conditions. Therefore *trimming tabs,* to balance the airplane, are coming into increased use. A tab is a small adjustable surface located at the trailing edge of a movable control surface (see Fig. 123). The air load on the tab produces a moment of force about the control hinge and thus deflects the main control surface, thereby producing a control moment without the exertion of effort by the pilot. The tabs may be adjustable on the ground only, as is usually the case with aileron tabs, or may be adjustable in flight at the will of the pilot, as is frequently the case with rudder and elevator control tabs.

The following photograph shows the location of elevator and rudder tabs on the tail assembly of a modern, large plane. It should be noted here that some (not all) airplanes are equipped with rudder tabs, aileron tabs, or both to provide for flight trimming about the vertical and longitudinal axes respectively.



Courtesy United Air Lines

Fig. 124. Tail control surfaces

Another type of auxiliary control is the wing flap, which is located, in monoplanes, on the trailing edge of the wing, between the ailerons and the fuselage. On biplanes, the flaps are usually on one wing and the ailerons on the other. The flaps are lowered on both sides at the same time, and in this respect are different from ailerons.

There are several types of flaps commonly in use. The accompanying illustration shows five types, indicating their position both when raised and when lowered. It is interesting to note that both Zap flaps and Fowler flaps increase the wing area as well as the camber of the wing.

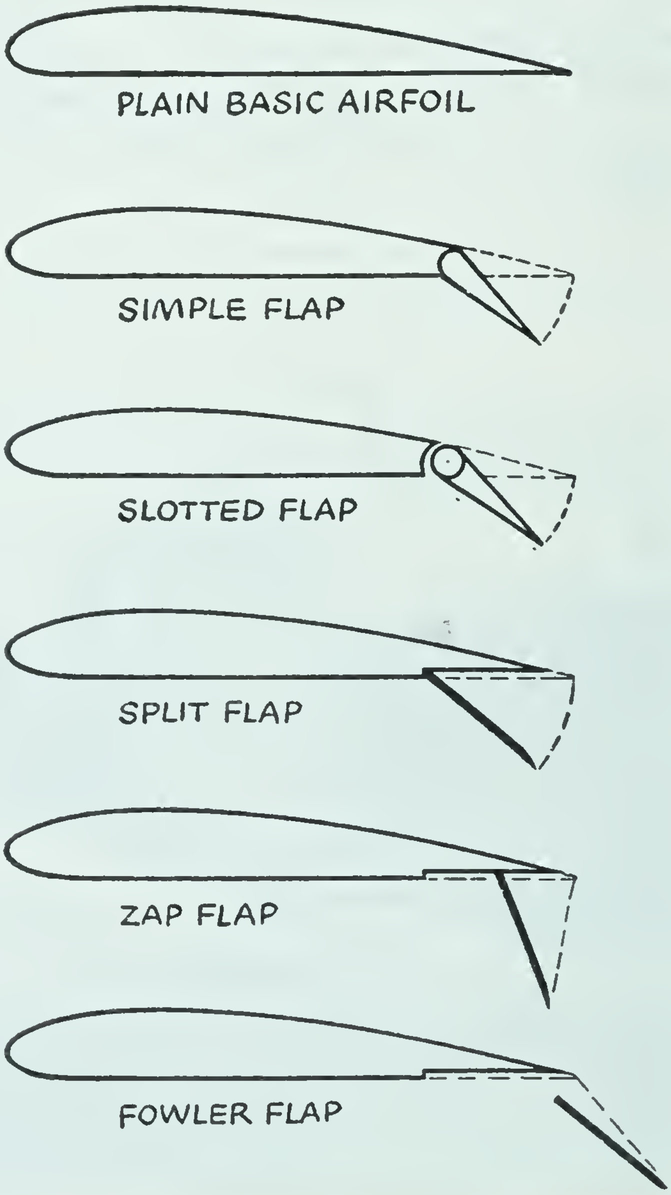
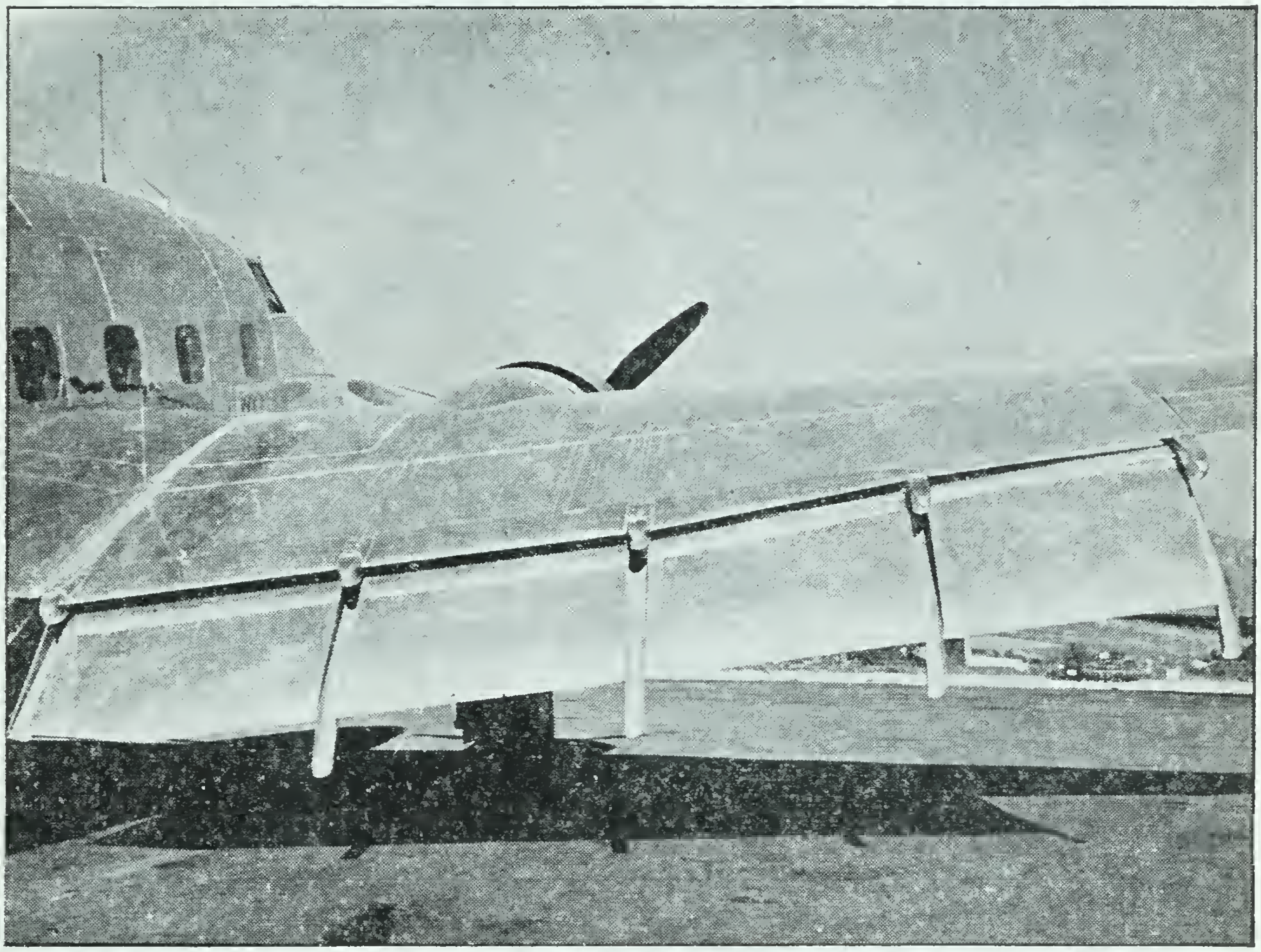


Fig. 125. Types of flaps

Flaps have several advantages: they permit slower landing speeds because of increased camber and the subsequent increase in lift; they permit a steeper gliding angle without an increase in speed, thus making possible landings on smaller fields surrounded by obstructions; and they make possible a shorter ground run in a landing operation. On the other hand, wing flaps have several disadvantages: they require an added pilot technique and add to the duties of the pilot; they make it more difficult to control the flight path; and they increase the weight of the plane.



Courtesy Lockheed Aircraft Corporation

Fig. 126. Fowler landing flap extended on inboard trailing edge of a Lockheed Lodestar Transport

Still another auxiliary control surface, used on some planes, is the slotted wing, which, in some measure, controls the boundary layer of air over the surface of the wing. The slot is advantageous in that it greatly increases the lift for large angles of attack and, at the same time, decreases the drag. Thus the introduction of the slot increases considerably the angle of attack at which burbling occurs. Figure 127 illustrates several types of wing slots.

Exercise 64. Give a reason or cause for each of the following conditions in an airplane: (1) nose heaviness; (2) left wing heaviness; and (3) a tendency of the plane to turn to the left.

Exercise 65. What is a stall? Why is a stall dangerous at low altitudes? Explain.

Exercise 66. Summarize the surfaces and forces that tend to maintain longitudinal, lateral, and directional stability in an airplane.

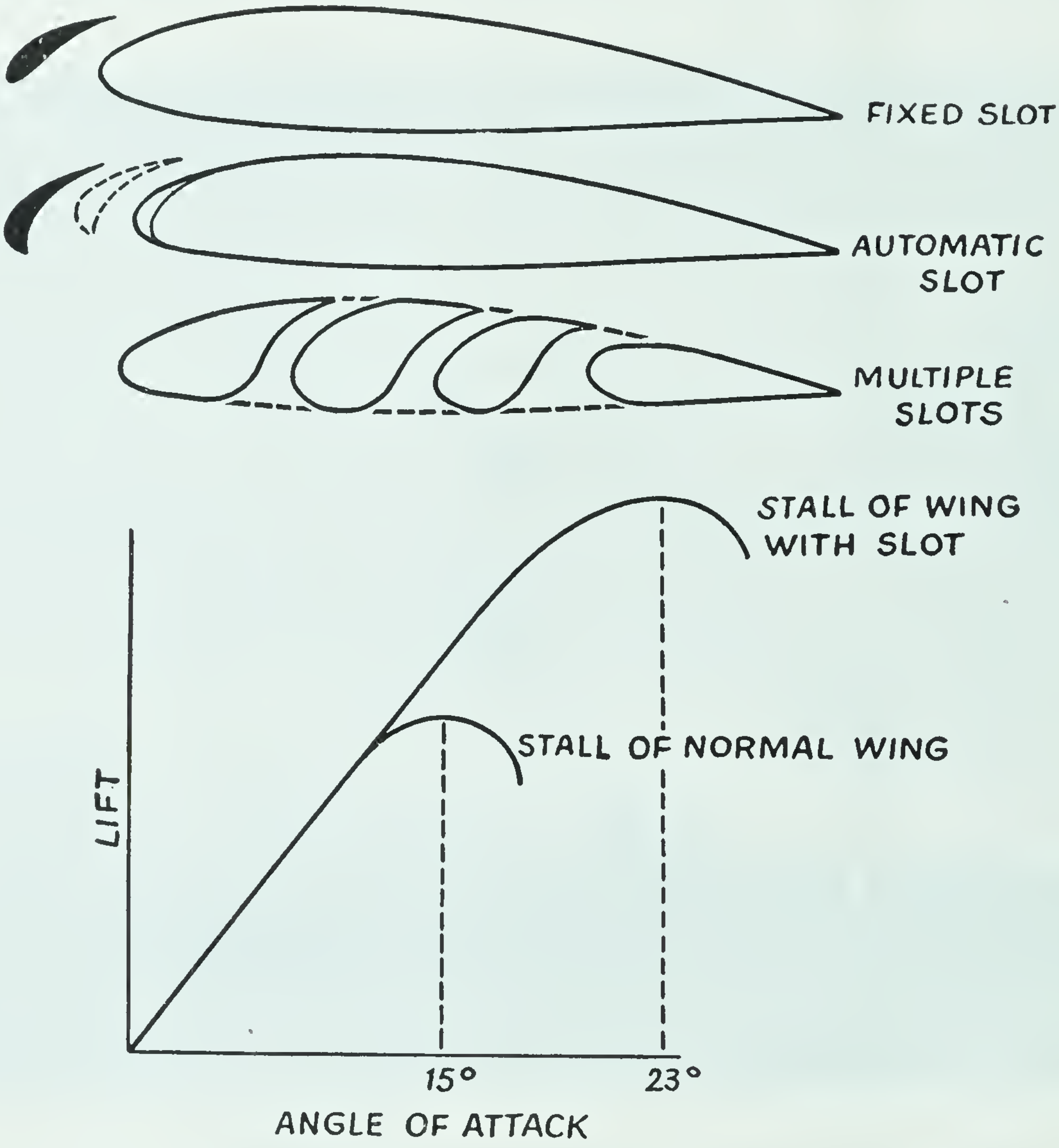


Fig. 127. Types of wing slots. The graph shows the effect of the slot on lift coefficient

Application Activities

1. What is the effect of changing the aspect ratio of a wing? Why must gliders have large aspect ratios?

2. Name the essential parts of an airplane and give the purpose of each.

3. What are the differences between the center of gravity and the center of pressure of an airplane? Discuss.

4. What forces act on a plane during a turn? A turn of 80° of bank cannot be maintained safely. Why? Discuss.

5. What effect does ice formation on the wing have on the performance of an airplane? Explain. Find out how ice is prevented from collecting on a wing.

6. Explain how lift, drag, and thrust are related to atmospheric pressure.

7. What are the differences and similarities of glider and airplane flight?

8. A glider constantly falls. How, then, can it rise?

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UNIT IV

THE POWER THAT DRIVES THE PROPELLER

Exploratory Activities

1. Make a list of all the different parts of an automobile engine of which you can think. Which of these would you consider to be essential in an airplane engine? Why?

2. What is the greatest number of engines ever mounted on an airplane? What is the most common number?

3. What is the nature of an explosion? Have you ever seen an automobile or airplane engine undergo an explosion? If so, what effect did it have on the engine?

4. Why do operators of automobiles occasionally change the oil in their engines? Why do they add oil between changes? Why do they use a different grade of oil in summer than in winter?

5. What would you consider to be some of the desirable characteristics of an airplane engine?

6. Describe the system of cooling usually used in automobile engines. Compare this with the system or systems of cooling commonly used in airplane engines.

Overview

The improvement of the steam engine by James Watt in 1763 marked the beginning of the rapid development of heat engines. From that day on progress was pronounced. The modest steam engine grew into a mighty locomotive that thundered across the plains of western America. The steam engine, however, had the disadvantage of great mass and size. In addition, it usually required a heating unit, an expansion unit, and various connections. For this reason it was entirely unfit for any purpose where light weight and economy of space were essential, such as in an airplane.

The development of the gasoline engine marked a new era in the history of heat engines. The gasoline engine burned its fuel inside the cylinder and thus could do away with the heating unit and the cumbersome connections of the steam engine. Consequently, it was much lighter and more efficient, because there was no loss of heat through pipes. Moreover, gasoline was lighter and could be more completely burned than the coal or wood commonly used in steam engines. The perfection of this type of engine represented a distinct step in the establishment of rapid transportation both on land and in the air. In fact, the entire development of flight has been and still is dependent upon the development of light, compact power plants.

The automobile engine and its first cousin, the airplane engine, have a great number of similarities, since they both operate on the same four-stroke cycle principle. However, the outstanding features of modern airplane engines are their lighter weight, greater endurance, and efficiency as compared with automobile engines. Airplane engines not so many years ago had to have a complete overhaul after every seventy-five hours or less of flying. Modern engines can operate 600 hours or more without overhaul. Such a figure does not mean much to the layman unless he stops to consider that if a plane averaged only one hundred miles an hour for 600 hours, it would have traveled 60,000 miles. How many automobile engines can boast of a record of 60,000 miles between overhauls? Furthermore, the airplane engine is operated at higher power output than is the automobile engine and, consequently, has a greater strain placed on it.

As with all great and complex inventions, the airplane engine cannot be attributed to the inventive genius of any one man. It has developed as the refined product of the inventive genius of many men. The giant airliners, long distance bombers, and fast pursuit ships have all been the result of years of arduous and painstaking labor and experimentation.

The airplane engine is composed of a number of units, all of which must work harmoniously together. If one unit fails to do its part, the entire engine must fail, and if the engine fails, a forced and sometimes hazardous landing must be made. For this reason, it is essential that the pilot and mechanic know the parts of a motor and how they work. A pilot is more likely to be successful if he knows his power plant. A common saying among pilots is, "Take care of your motor and it will take care of you."

In this unit we shall endeavor to learn the importance of each part of the airplane engine, how the various parts interact, and the care to which each is entitled.

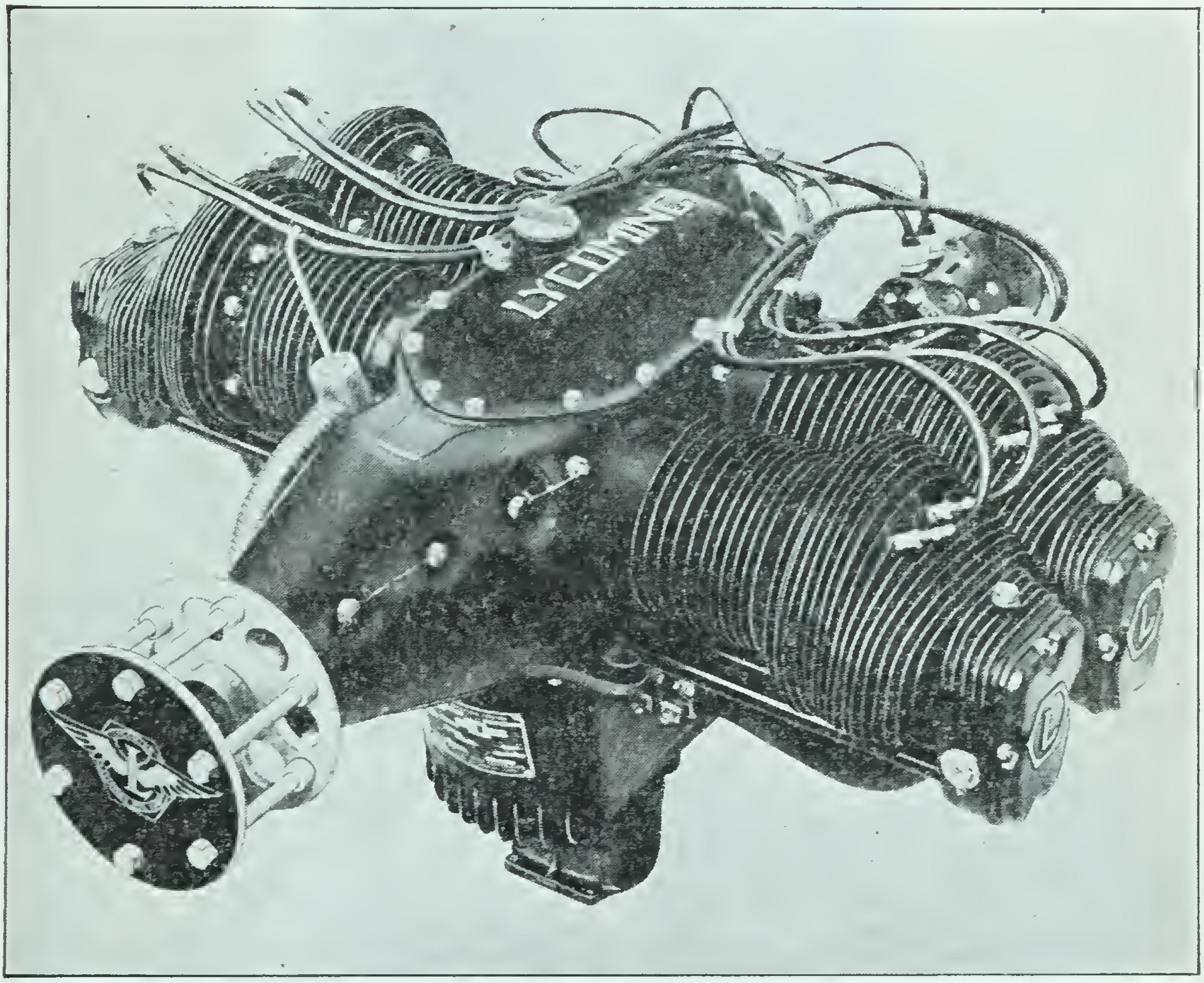
Problem 1. How do airplane engines differ from each other?

Airplane engines are classified either according to the method of cooling or on the basis of the cylinder arrangement. While nearly all automobile engines are liquid-cooled rather than air-cooled, airplane engines may employ either system of cooling. When the liquid system is employed, it is very similar to that of the automobile engine except that ethylene glycol is used as a coolant. On the other hand, the method of utilizing air as the cooling fluid varies somewhat with cylinder arrangement. Since air cooling is not used extensively in automobile motors, its use may be regarded as more suited to the conditions of air travel than of land travel.

Whereas automobile engines in the main are built along the same general pattern of cylinder arrangement, airplane engines vary considerably in this respect. In automobile engines the cylinders are either in a straight line behind the radiator or in the form of a V in a double line. In either case the cylinders are mounted and operate above the crankshaft. Airplane cylinders may be mounted in a similar manner or in an inverted position, with the crankshaft above the cylinders. Furthermore, the cylinders of an airplane engine may be mounted horizontally on opposite sides of the crankshaft, or they may be arranged in a circle around the crankshaft. In general, airplane engines are divided into four classifications on the basis of cylinder arrangement: the *opposed* engine; the *radial* engine; the *in-line* engine; and the *V-type* engine.

Opposed engines are air-cooled and usually consist of four cylinders (two pairs) mounted horizontally on opposite sides of the crankshaft. Small privately owned planes are usually powered by engines of this type. The opposed engine is very widely used in light aircraft because of its low cost, reliability, simplified maintenance, and the fact that it allows better cockpit visibility. Four-cylinder opposed engines are capable of developing from forty to eighty horsepower. The Franklin Company has recently produced an opposed engine with six cylinders and power ranging from 117 to 120 horsepower.

Radial engines are air-cooled and may have as few as three or as many as eighteen or more cylinders. A true radial engine, however, must have an odd number (3, 5, 7, 9, or possibly 11) cylinders. Fourteen- and eighteen-cylinder "radial" engines are in reality two engines attached to the same crankshaft. Because of the large number of cylinders that can be built into it, the radial engine is one of the most powerful engines of its size. The Wright Duplex Cyclone engine has eighteen cylinders and will produce as much as 2000 horsepower. Radial engines get their name from the fact that the cylinders radiate from the crankshaft much as the spokes of a wheel radiate from the hub. They may employ either a single row or a twin row of cylinders. The single row engine is comparable to one wheel with its spokes, and the twin row compares with two wheels, one beside the other on the same axle. The radial engine is used in America more extensively than is any other type of engine.

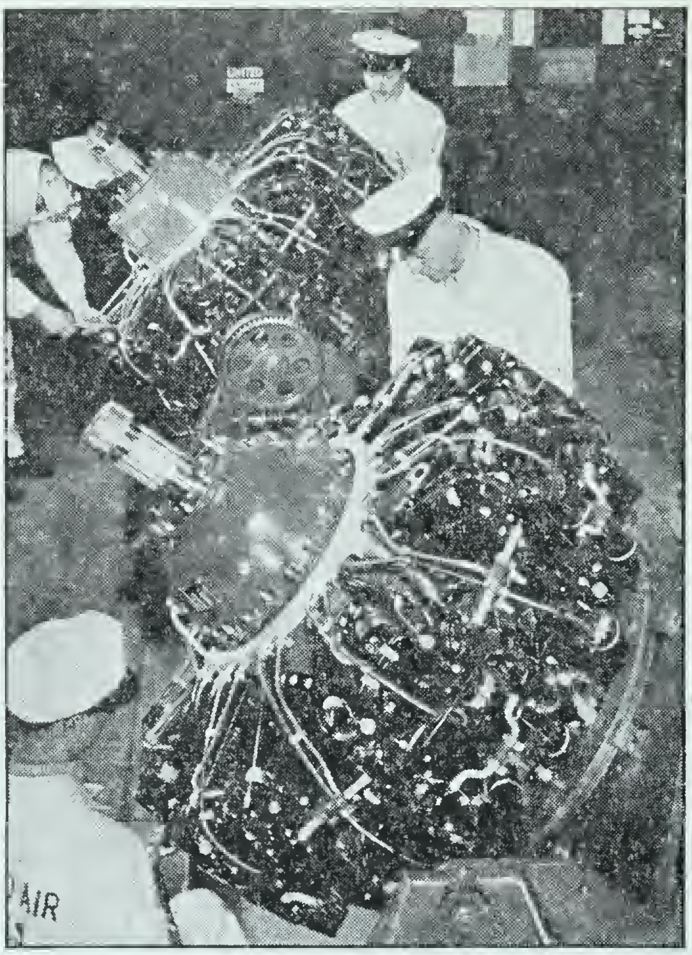


Courtesy Lycoming Division of Aviation Corporation

Fig. 128. A four-cylinder opposed engine

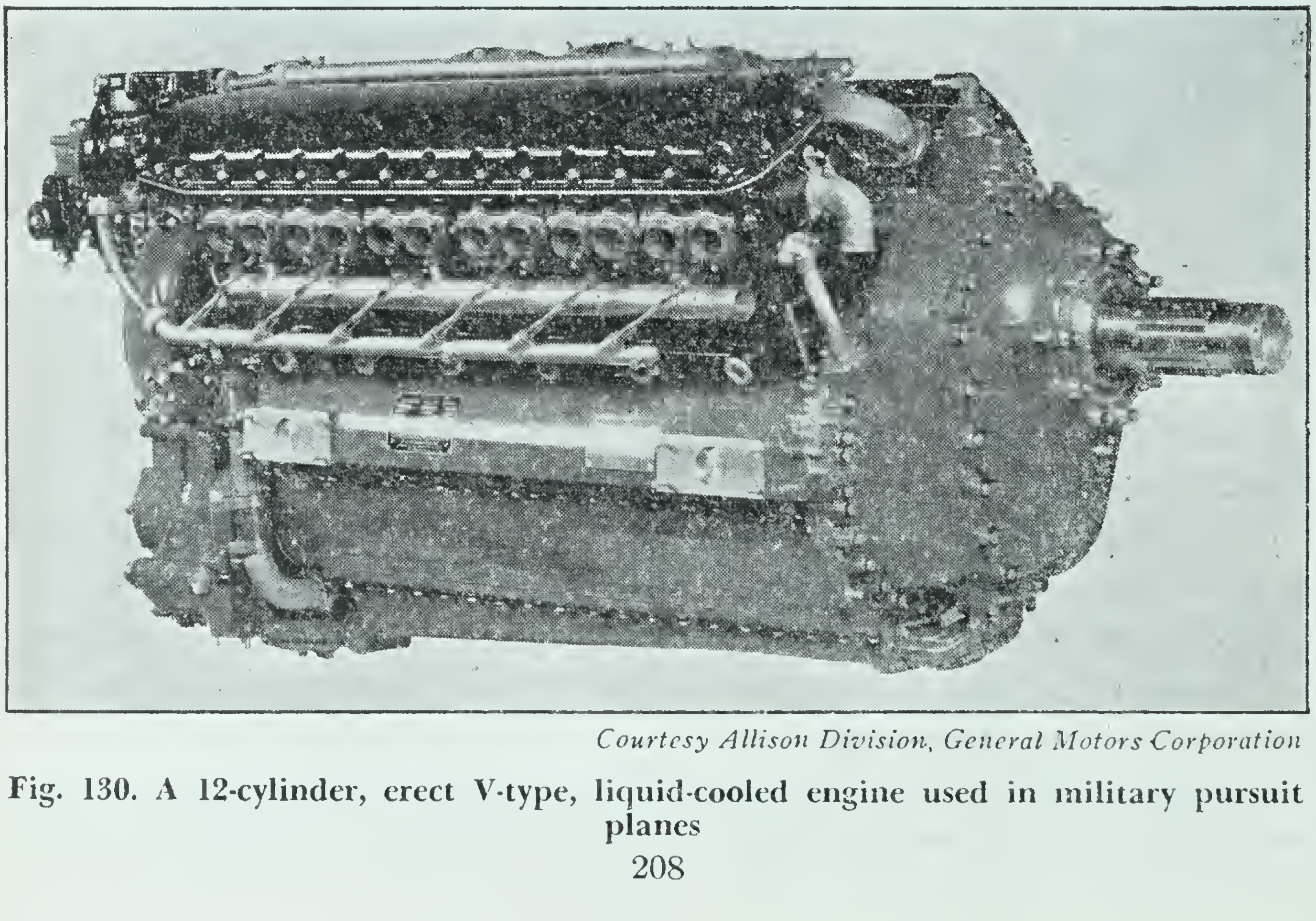
In-line engines may be either air-cooled or liquid-cooled, depending on the number of cylinders and their size. They may be either vertical (as in automobile engines) or inverted with the crankshaft above the cylinders. The cylinders are all arranged in a straight line parallel to the crankshaft.

V-type engines may be either air-cooled or liquid-cooled, and are variations of the in-line type, with the cylinders arranged in two



Courtesy United Air Lines

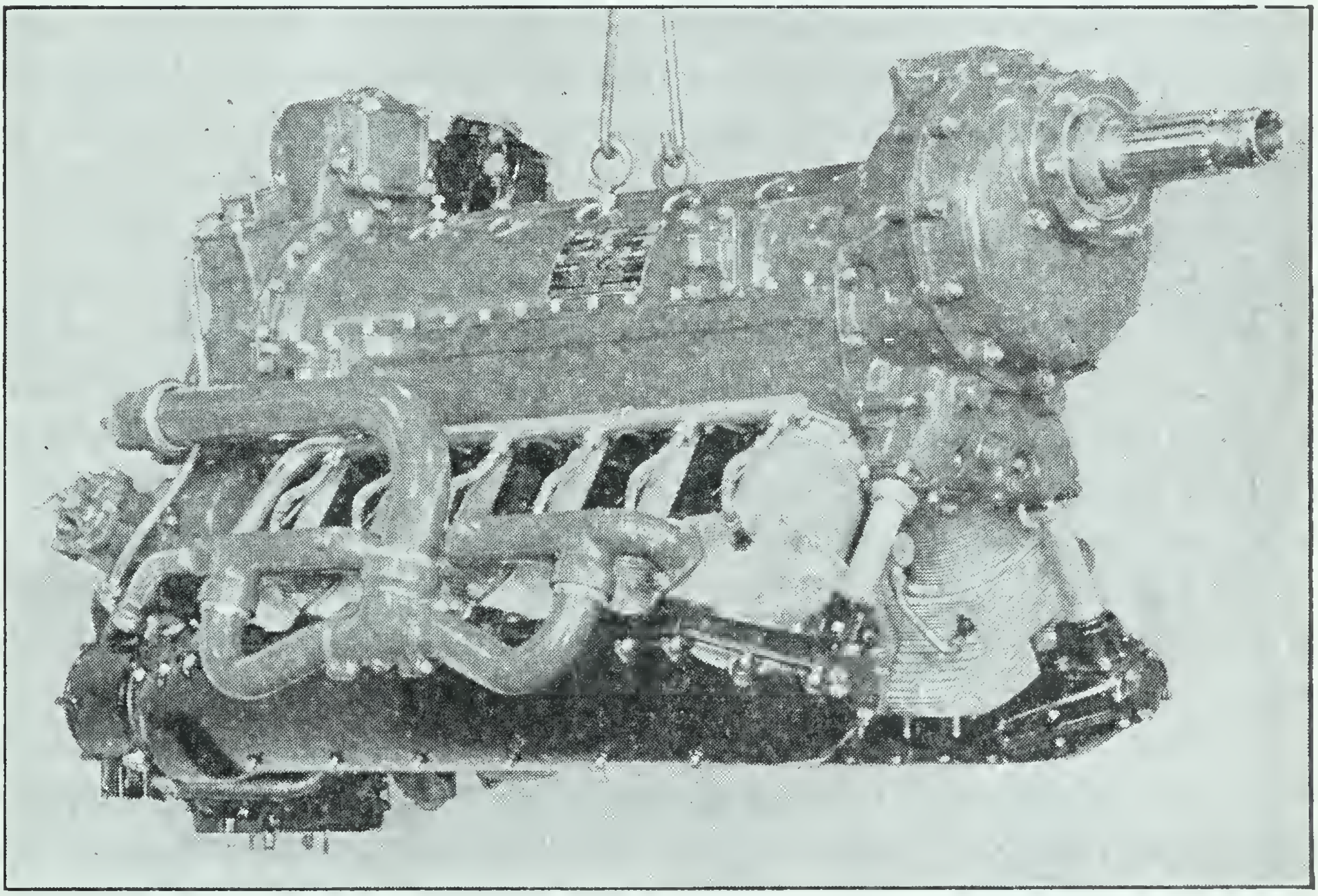
Fig. 129. Two 1250-horsepower, 14-cylinder, twin-row, radial engines



Courtesy Allison Division, General Motors Corporation

Fig. 130. A 12-cylinder, erect V-type, liquid-cooled engine used in military pursuit planes

"in-line" banks set at an angle to each other. Viewed from one end, the engine appears in the form of a V or an inverted V depending on whether or not the engine is a vertical or an inverted type. One of the most recent developments in V-type engines is the Allison V-3420 engine which was displayed in the General Motors Corporation exhibit at the New York World's Fair in 1939. This engine has twenty-four cylinders arranged in four rows of six cylinders each and can produce 2000 horsepower. It is essentially two twelve-cylinder, V-type engines geared to the same propeller shaft.



Courtesy Ranger Aircraft Engines

Fig. 131. An air-cooled, 12-cylinder, inverted V-type engine

Exercise 1. Aircraft engineers design planes around engines, not engines to fit planes. Discuss.

Problem 2. How is power produced and transferred in the airplane engine?

The internal-combustion engine. All present-day airplane engines burn and expand their fuel within the cylinders of the engine. For this reason they are called internal-combustion engines. Both Diesel and gasoline engines are included in this group, but our consideration here is confined to the gasoline engine. While Diesel airplane engines are being used somewhat in Europe, they are still more or less in the experimental stage insofar as their use in aircraft is concerned. Steam engines as sources of power in aircraft have long been abandoned because of their great mass and size. When the fuel is burned inside the cylinders of a gasoline engine, a very high temperature is attained, and, as a result, considerable power is developed. Before we can fully understand the nature of this power, it is necessary to know something of the nature of matter and of heat.

The molecular nature of matter. When we speak of matter, the term implies anything that has weight and occupies space. All solids, liquids, and gases are matter, for they can all be weighed. In our study of engines, it will be necessary for us to consider all three types of matter. Physicists and chemists have collected evidence which indicates that all matter is made up of molecules. Let us consider a drop of water. It is possible to divide that drop into two smaller drops. If, then, one of these drops could be divided again and again until it could no longer be divided and still remain water, the smallest particle obtainable would be a molecule of water. A molecule is defined as the smallest particle of a substance that can exist and still retain all the characteristics of that substance. Molecules may differ in size, but even the largest ones are invisible to the ordinary microscope.

It has been found by experiment that under normally obtainable conditions all molecules are in motion. Molecules of gases are farther apart than those of liquids, and the molecules of solids are the closest together of the three. Since the molecules are crowded together and moving, it is inevitable that they should collide with each other and rebound. Scientists have evidence to show that when most materials are heated, the molecules of those materials move faster and faster away from each other. Heat is defined in physics as the energy of motion of the molecules of a body. The power of the gasoline engine is developed by the increased motion of the molecules of gas when the fuel is burned in the cylinders.

Expansion of materials by heat. If a substance increases in volume and occupies more space, it *expands;* and if a substance decreases in volume, it *contracts.* When a gas is heated, it has a tendency to expand because the molecules of which it is made move farther apart. Let us assume that there is no place for the gas to go, and it cannot expand. The moving molecules will set up a continuous bombardment against the walls of the container, much like bees that again and again strike a screen in an effort to escape. Moreover, the hotter the gas, the greater the speed of the molecules and the greater the force they exert on the walls of the container. That the force of impact depends upon speed can be easily seen if one considers, first, a baseball slowly tossed to the catcher and, then, a speed ball going so fast that it can hardly be seen. In an inclosed gas the continual molecular bombardment of the walls of the container set up a constant pressure that increases with the temperature. If, however, the container is closed on one end by a movable piston, the molecular bombardment will tend to force the piston out of the container. This is exactly what happens in the cylinder of the internal-combustion engine.

Laboratory Exercise 2. Place about a half-inch of water in a thick-walled pyrex test tube and cork it looosely. Heat the water in the test tube over a burner. CAUTION: Be sure that the mouth of the tube is not pointed toward anyone and that the cork is not too tight. Explain the results.

Laboratory Exercise 3. Blow up a toy balloon, place a few drops of gasoline or ether in a wide-mouthed jar, and cover the jar with the balloon. Let the apparatus stand for ten or fifteen minutes, and then let the air out of the balloon into a student's face. The odor of the gasoline or ether will be noticeable in the air from the balloon. How did the odor get inside the balloon?

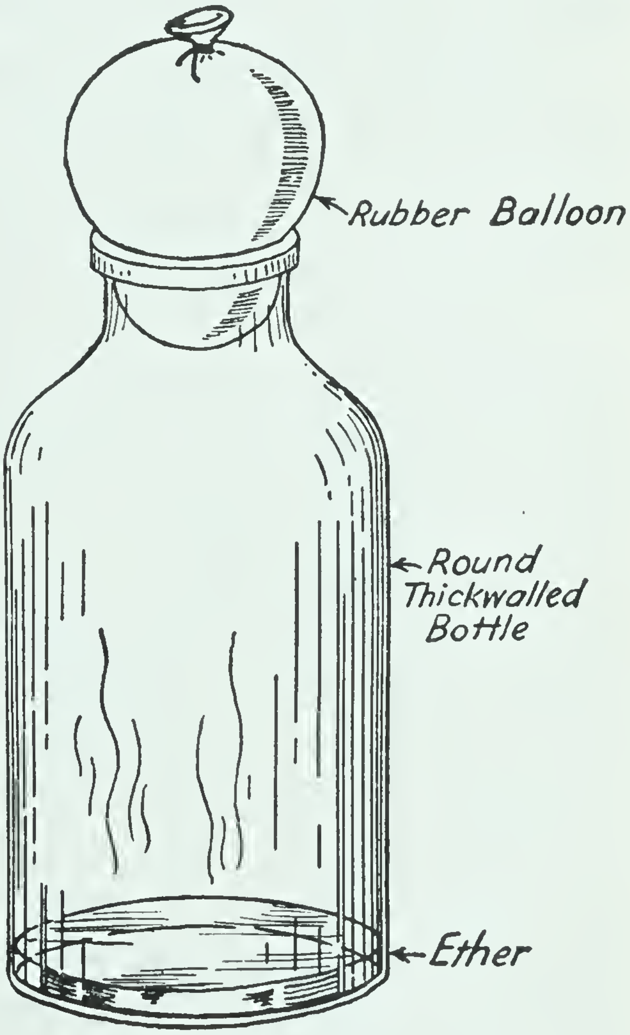


Fig. 132

Laboratory Exercise 4. Place a few drops of ammonia in a large-mouthed bottle and cover the bottle with a piece of moist filter paper. Place a lamp chimney over the mouth of the bottle so that it rests on it. Cut a slit in the small end of a cork of a size to fit the upper end of the lamp chimney, and insert a strip of moist red litmus paper in the slit. Cork the lamp chimney and allow the apparatus to stand for a few minutes. Explain results. (Note: Moist red litmus will turn blue in the presence of ammonium hydroxide or other alkalies.)

Laboratory Exercise 5. To illustrate the internal-combustion principle, it is recommended that the *teacher* perform the following experiment, which is not dangerous if due caution is observed as here outlined. It demonstrates how the explosion of gasoline produces power.

a. Obtain a tin can with a tightly fitting friction (not screw) cover. A baking-powder or corn-syrup can is good. Punch a nail hole about the size of a pencil about halfway up the side of the can. Place the can on a stand, so that one candle can be put under it and another candle just outside the hole. Do not put the candles in position yet.

Pour five drops—*no more*—of gasoline (or about eight drops of ether) into the can and put on the cover. Cork the gasoline bottle tightly and place it at least 10 feet away.

Now place the can on the stand. After lighting the candles, put one of them in place under the can and the other outside the hole, *keeping the face carefully away from the can and the hands away from the cover.* In a very few seconds there will be a loud explosion and the cover of the can will fly up toward the ceiling.

b. To demonstrate that gasoline will not explode if it is not confined, pour five drops into a saucer and set fire to it with a burning soda straw. It will be observed that the alcohol burns quickly but does not explode. Be sure to place the gasoline bottle at a safe distance, as you did before.

The four-stroke cycle and valve action. Although airplane engines are all made up of several cylinders, it will be necessary for us to consider the action in only one cylinder in order to understand the way in which all of them work. The parts which we must consider at this time are: the *cylinder,* which is a round tube, similar in shape to an oatmeal box, closed at one end; the *piston,* which closes the other end of the cylinder and is free to slide back and forth in the cylinder; the *intake valve,* which allows a mixture of gasoline vapor and air to enter the cylinder from the carburetor; and the *exhaust valve,* which allows the burned waste gases to leave the cylinder after the fuel has been burned. These parts all function together and are timed so that their action occurs at regular intervals. The piston is connected directly to the crankshaft by means of a connecting rod and slides up and down in the cylinder as the crankshaft revolves.

Each piston moves up and down twice (traversing the length of the cylinder four times) for every explosion of gasoline vapor in the cylinder. Each time the piston moves up or down it performs a useful act which enables the cylinder to fire again, and the four strokes the piston makes in order to fire once are called the *four-stroke cycle.* The four strokes occur in the following order:

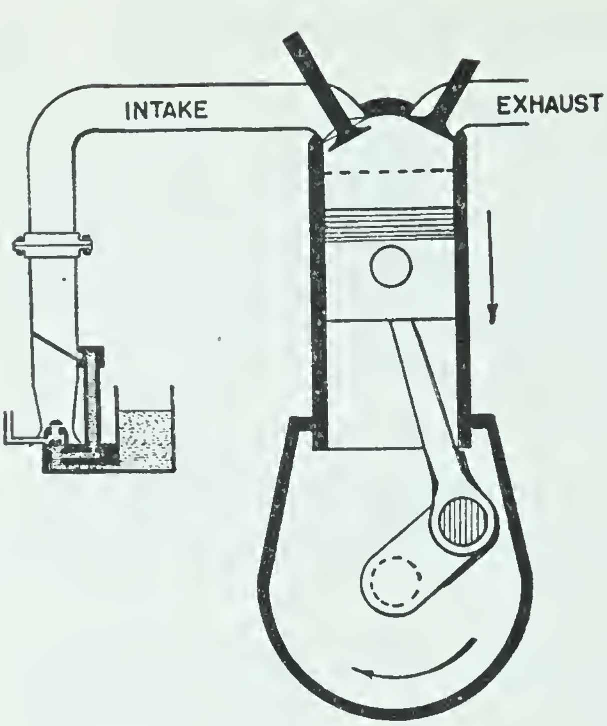
1. *Intake stroke:* As the piston moves down from the top of the cylinder, the intake valve opens and the partial vacuum formed by the descending piston causes the fuel mixture from the carburetor to be drawn into the cylinder.

2. *Compression stroke:* When the piston reaches the bottom of its downward stroke it starts up again and compresses the mixture of gasoline vapor and air in the cylinder. The mixture is compressed in aircraft engines to from one fifth to one eighth of its former volume. During the compression stroke both valves are closed; otherwise, the mixture would be forced out of whichever valve was open and would result in a loss in power. When a gas is compressed, it becomes hot, and the temperature increases with increase in pressure. It is necessary, therefore, that the mixture not be compressed too much, for the temperature then would be high enough to cause an explosion before the piston reached the top of its compression stroke, and this would also result in a loss of power.

3. *Power stroke:* Just before the piston gets to the peak of its compression stroke, the spark ignites the compressed fuel mixture, and, as the fuel burns, the piston is forced down by the expansion of the hot gases formed. It is well to note here that the piston supplies power for only about one sixth of the time it is in motion, and for the other five sixths it "drags its feet." During the power stroke, as in the compression stroke, it is necessary that both exhaust and intake valves be closed, to enable all of the power to be expended on the piston. When the fuel is burned, it develops an extremely high temperature; and, consequently, a cooling system is necessary. This will be discussed later.

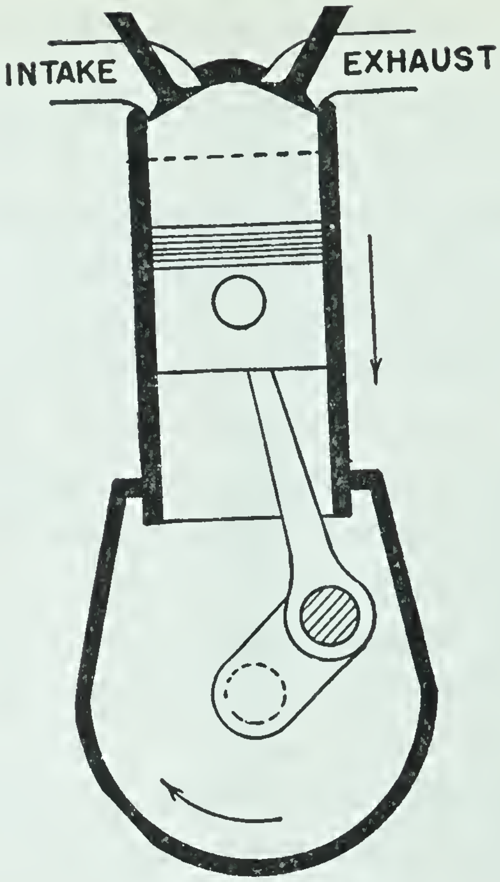
4. *Exhaust stroke:* Before the piston can fire again the waste gases must be removed from the cylinder. On the fourth, or exhaust, stroke the exhaust valve is opened, and as the piston moves upward the exhaust gases are forced out. After the exhaust stroke, the intake stroke begins again.

In airplane engines the valve action is so timed that the intake valve is opened a short time before the piston completes the exhaust



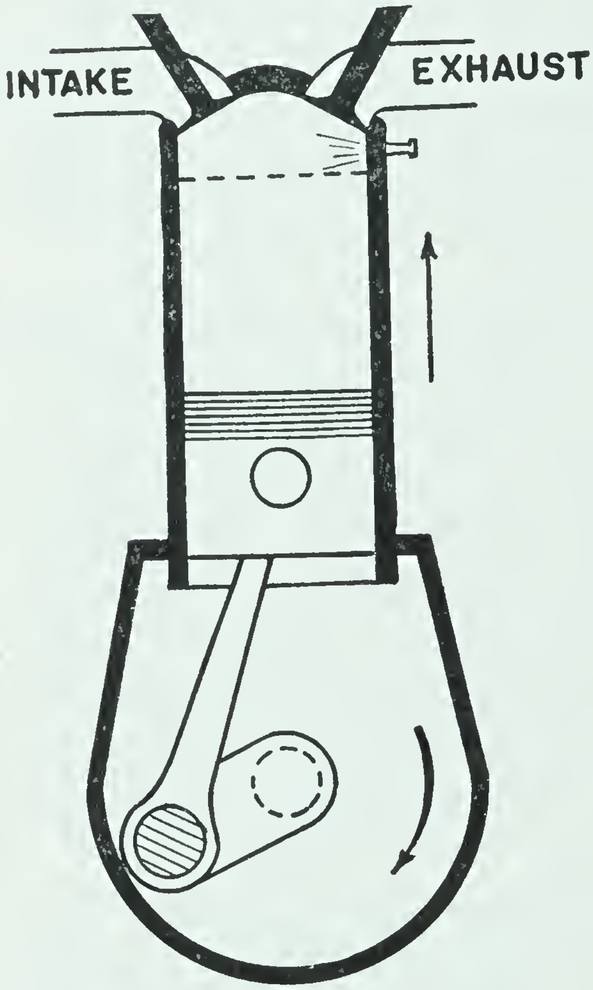
INTAKE STROKE

EXHAUST VALVE CLOSES APPROXIMATELY
8° TO 35° A. T. C.



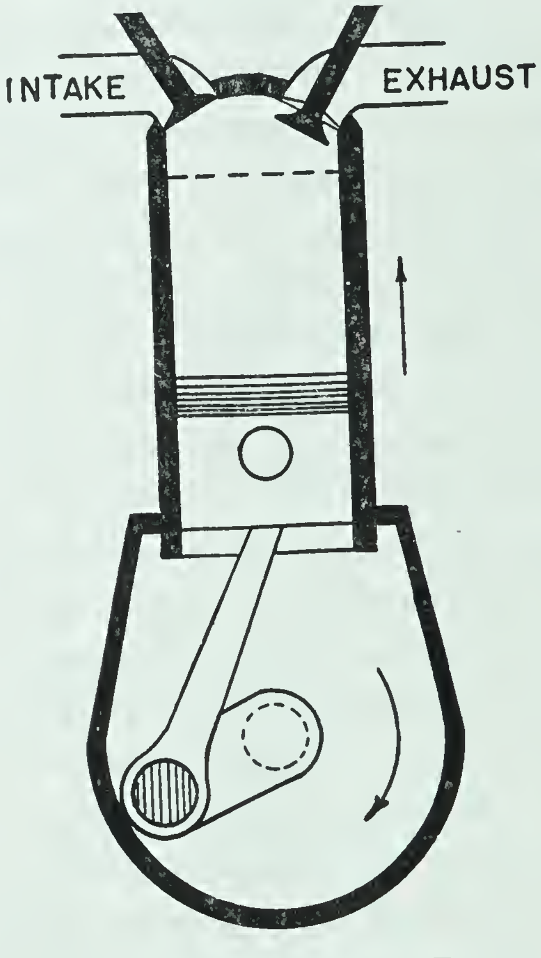
POWER STROKE

EXHAUST VALVE OPENS APPROXIMATELY 50° TO 75° B. B. C.



COMPRESSION STROKE

INTAKE VALVE CLOSES APPROXIMATELY 45° TO 75° A. B. C.
IGNITION FIRES 20° TO 35° B.T.C.

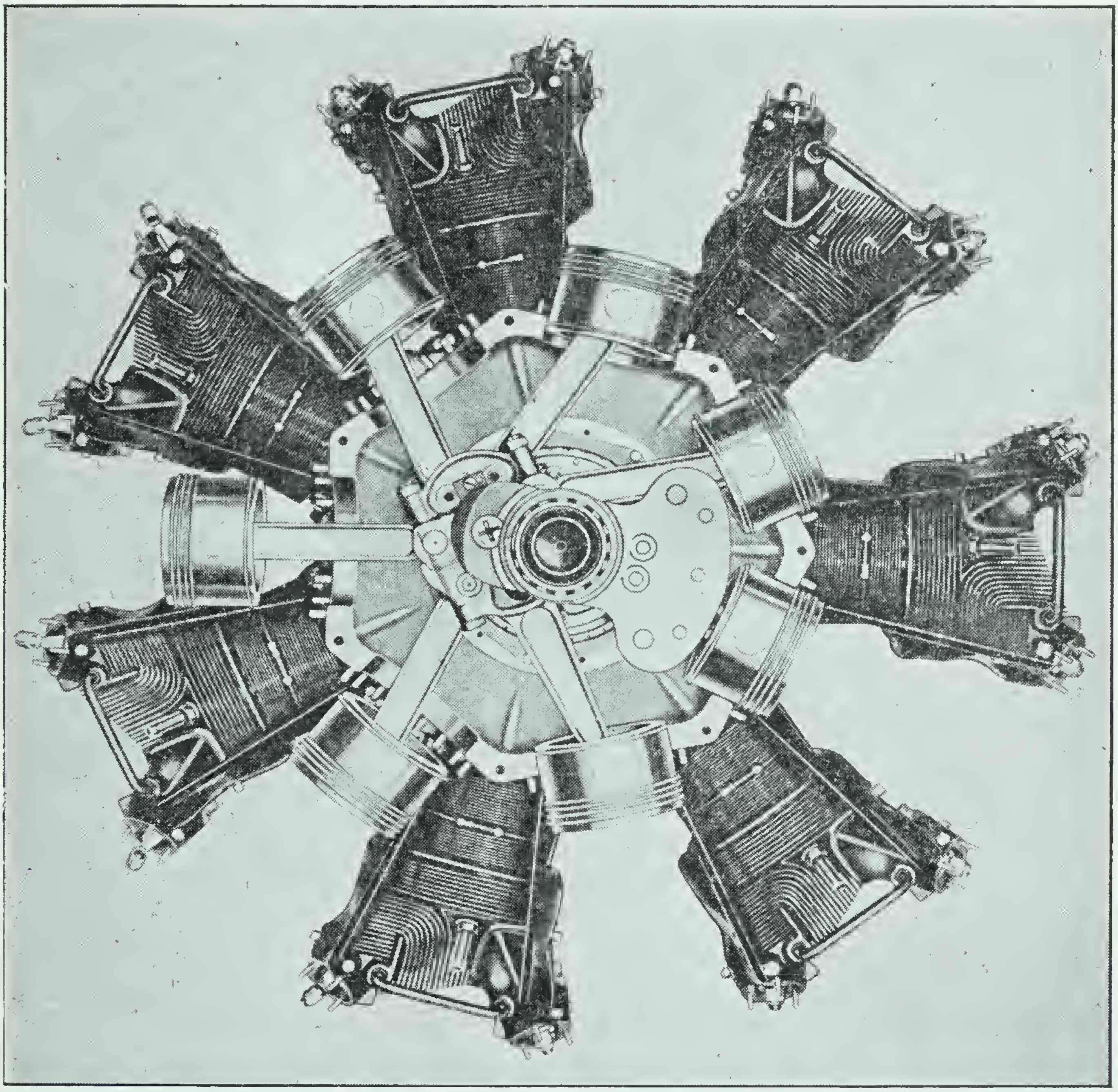


EXHAUST STROKE

INTAKE VALVE OPENS APPROXIMATELY 8° TO 30° B. T. C.

Fig. 133. Four-stroke cycle of an internal-combustion engine

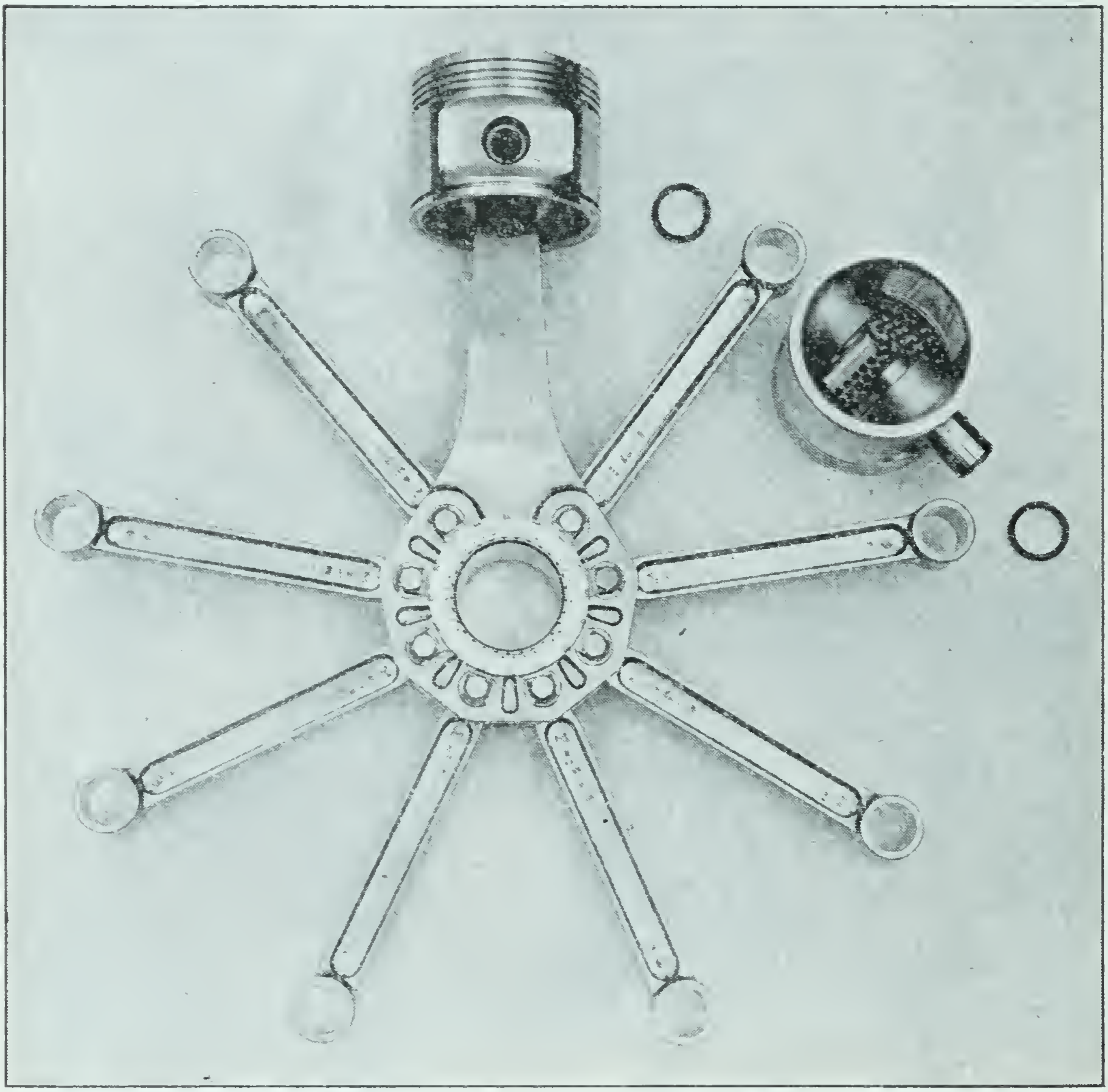
stroke and is closed a short time after the compression stroke begins. The exhaust valve is opened a short time before the piston gets to the bottom of its power stroke and is closed a short time after the intake stroke begins. This is to allow for the lag of the gases due to their mass and inertia. It has been found by experiment that, if the intake valve closes a considerable number of degrees of crankshaft rotation *after* the compression stroke starts, advantage can be taken of the momentum of the intake mixture because of its velocity, and more fuel mixture will enter the cylinder. On the other hand, the increased



Courtesy United Aircraft Corporation

Fig. 134. This picture illustrates the relative positions of pistons, link rods, master rod, and crankshaft at one point in the cycle of operation of seven-cylinder Pratt and Whitney radial air-cooled engine

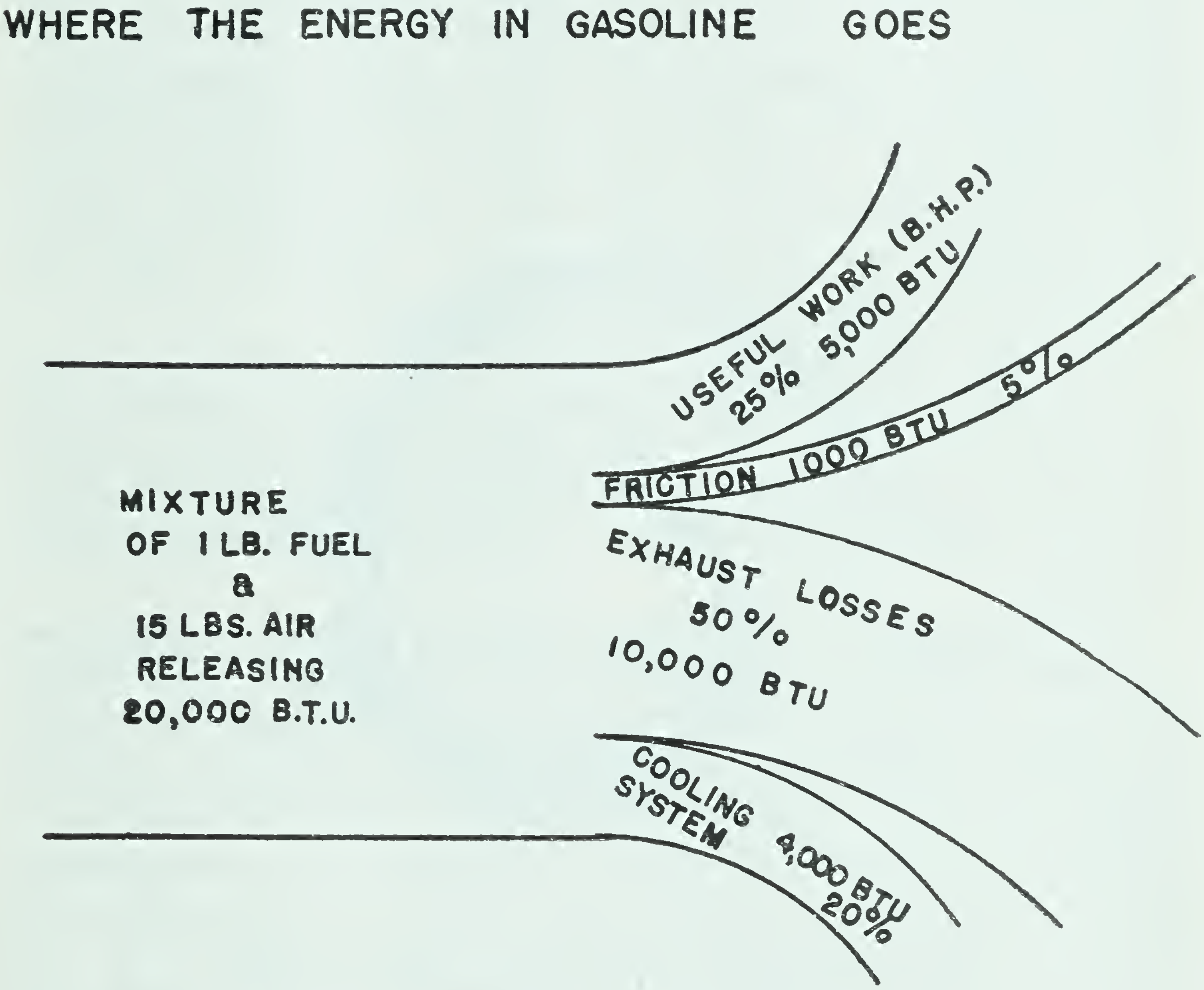
velocity of the gases passing out of the exhaust valve creates a momentum which later causes a reduced pressure in the cylinder. This reduced pressure of the exhaust gases is used to accelerate the flow of fresh mixture into the cylinder if the intake valve is opened before the end of the exhaust stroke. The cooler incoming mixture helps to force the exhaust gases out and at the same time helps to cool the interior of the cylinder.



Courtesy Wright Aeronautical Corporation

Fig. 135. Master and articulated rods of a nine-cylinder radial engine. Note the cooling fins within the piston at the right and the method of attaching the piston to the rod

The transfer of power in a motor. The word *power* indicates how much work can be done in a given length of time. In other words, the time element distinguishes work from power. The common unit of power is the horsepower, which is the power necessary to lift 33,000 pounds a distance of one foot in one minute. The maximum horsepower of popular automobile engines on the average varies between 75 and 165. The horsepower of airplane engines may be as low as 40 or as great as 2000 or more. As we have already seen, power is developed in the internal-combustion engine by the expansion of gases in the cylinder. The piston moves up and down in the cylinder in a straight path, whereas the crankshaft moves in a circular path. It is evident that some means must be available to change the back-and-forth motion (reciprocating motion) of the piston to the circular motion of the crankshaft. This is accomplished by means of various connections. The piston is connected to the crankshaft by the *connecting rod,* or the articulating rod (see Fig. 134). The connecting rod is joined to the piston by means of a *piston pin,* which allows con-


WHERE THE ENERGY IN GASOLINE GOES
MIXTURE OF 1 LB. FUEL & 15 LBS. AIR RELEASING 20,000 B.T.U.
USEFUL WORK (B.H.P.) 25% 5,000 BTU
FRICTION 1000 BTU 5%
EXHAUST LOSSES 50% 10,000 BTU
COOLING SYSTEM 4,000 BTU 20%

HEAT BALANCE DIAGRAM FOR AVIATION ENGINE

Fig. 136

siderable freedom of motion in one plane. The connection to the crankshaft is through a bearing which allows the connecting rod to turn on the crankshaft. The rotation of the crankshaft is transmitted directly or by means of reduction gears to the propeller shaft.

Although most piston assemblies have the same general attachments, different cylinder arrangements have different patterns of articulation. In-line and opposed engines have much the same type of connection between pistons and crankshaft as that found in automobile engines, but radial engines differ in that as many as nine cylinders may be connected to the crankshaft at one point. This is accomplished with a master connecting rod to which are attached the link rods of the other pistons. In some V-type engines two pistons are connected to the crankshaft at the same point by a master rod and one link rod. (See Fig. 135.)

Since the airplane engine is a heat engine, the more heat which can be converted to mechanical energy of the piston, the more efficient the engine will become. Most of the heat developed is wasted in one way or another, and only about 25 per cent is utilized in doing useful work on the propeller. Figure 136 will best show what happens to the heat.

Advantages and disadvantages of different cylinder arrangements in airplane engines. An airplane engine is mounted on a framework that is light and relatively delicate. For this reason it is necessary that the engine operate with the smallest amount of vibration possible. In general, the greater the number of cylinders acting on a crankshaft, the smaller the amount of vibration. In a two-cylinder engine a crankshaft receives one push for each revolution, and as a result there are considerable vibration and jerk because of the distance the crankshaft must go between pushes. In a four-cylinder engine, the crankshaft receives two pushes for each rotation, and the engine has less time to slow down between pushes. In an eighteen-cylinder engine there are nine pushes for one revolution of the crankshaft, and the motion is much more uniform. The power impulses in this engine overlap in such a way that power is constantly applied to the crankshaft. (See Fig. 137.) In automobiles the engine is equipped with a flywheel which keeps it running smoothly between power impulses. To a certain extent the propeller serves the same purpose on an airplane engine.

It is important that the weight of the pistons on the crankshaft be exactly balanced by an equal weight on the opposite side of the crankshaft in order to reduce main-bearing loads. Opposed engines have equal numbers of pistons on opposite sides of the crankshaft and thus possess the desired balance.

On large radial engines, where the firing impulses are great, and where the entire piston assembly mass is concentrated on one or two crank throws, it is necessary to locate equal masses on the opposite sides of the crankshaft to obtain balance. This is accomplished by adding counterweights at such points.

High-powered engines with heavy propellers set up severe twisting forces, even though they are equipped with counterbalanced crankshafts. The *dynamic damper* is designed to counteract such forces. The simplest type of dynamic damper consists of a movable, suspended, slotted counterweight attached to the crank cheek by two spool-shaped pins which extend into the slot and also pass through oversized holes in both crank cheek and weight. Since the weight hangs loosely, there is created a pendulum effect, which effectively damps out torsional forces.

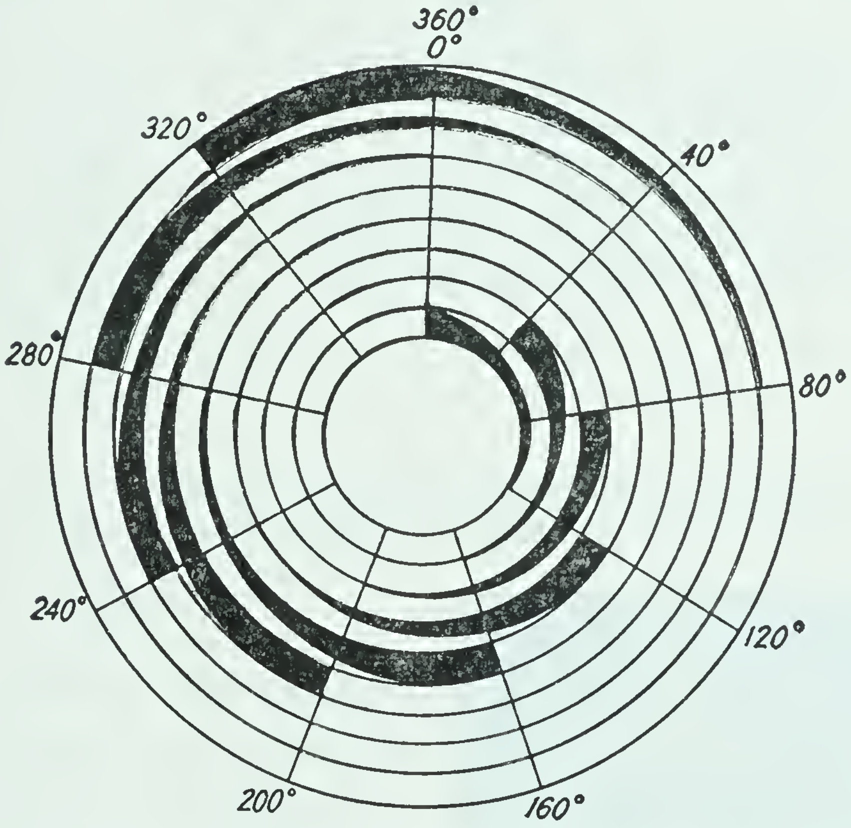


Fig. 137. Power overlap in one revolution of an eighteen-cylinder radial engine

Figure 138 explains how this damping effect comes about, while Figure 139 shows the method of mounting the weight on the crank cheek.

Engine vibration may be caused by many other deficiencies, the most common of which are unequal compression in the cylinders, unequal valve and ignition timing, lack of proper balance in the engine parts, and broken or loose engine-mount attachments.

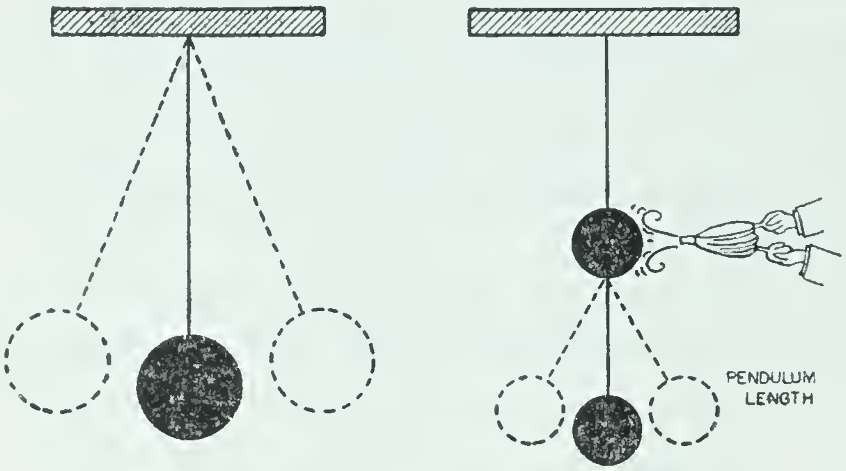


Fig. 138. Principle of operation of dynamic damper. If a pendulum is given a series of pushes at a speed corresponding to its natural period, it will start swinging back and forth. If a second pendulum is suspended from the first, it will absorb the impulses and start swinging, leaving the first stationary

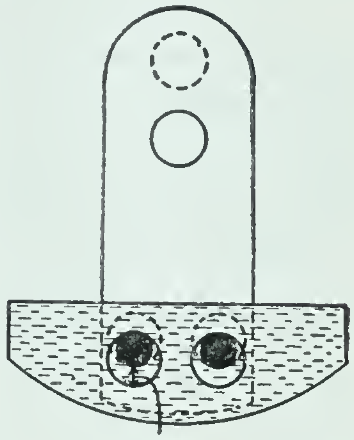
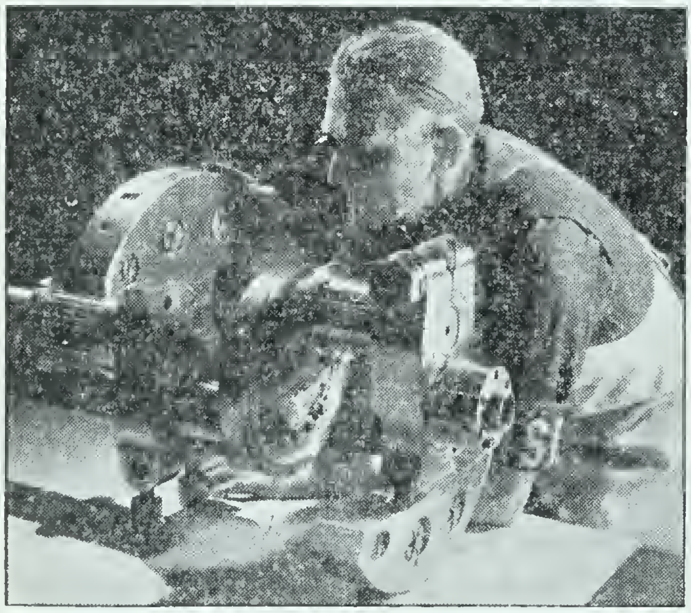


Fig. 139. Dynamic damper. The dynamic damper is, in effect, a short pendulum hung on the crankshaft and tuned to the frequency of the power impulses to absorb vibrations of the crankshaft



Courtesy Wright Aeronautical Corporation

Fig. 140. The complete crankshaft of a 14-cylinder radial engine showing the dynamic damper on the crankcheeks

To attain speed and efficiency it is essential to cut down the amount of resistance to airflow by streamlining. Because of differences in design some engines lend themselves better to streamlining than others do. The radial engine exposes the greatest frontal area to the slipstream of the propeller and, consequently, offers the greatest amount of resistance to the air. The flatter V-type engines, on the other hand, can be readily mounted in the wing of large planes and offer very little air resistance. Liquid-cooled in-line engines lend themselves readily to streamlining because of the small frontal area exposed, but the increased weight of the cooling system is a disadvantage. The streamlining of radial engines is greatly aided by the use of a cowling, which is comparable to the hood of an automobile engine and can be so arranged that the airflow will be directed past the engine in order to help cool it. Cooling systems have probably been one of the greatest hindrances to streamlining, but modern design has overcome this handicap to a great extent.

Two other factors that must be considered in cylinder arrangements are the accessibility to repair and vulnerability to gunfire in military operations. The radial engine has a better arrangement than do any of the others in these respects. The cylinders of a radial engine are mounted separately from each other and are much easier to reach than are the cylinders of an in-line engine or a V-type engine. The radial engine, moreover, is less vulnerable to air attack than is a liquid-cooled engine. Should the cooling system of a liquid-cooled engine be punctured at any point in such a way as to allow the liquid to escape, the engine would very quickly cease to operate because of too high temperatures in the cylinders. Extreme temperatures would cause the metals of the engine to warp out of shape or even to melt.

Exercise 6.

a. Report on mushroom, tulip, hollow stem, and salt-filled valves.

b. Report on the mechanism which lifts the valves in an in-line engine. In a radial engine.

Problem 3. How is fuel supplied to the airplane motor?

The purpose of the carburetor and its importance. One of the reasons that internal-combustion engines were not developed years before they actually appeared was the lack of a suitable fuel that could be burned within the cylinder. Long before the discovery of petroleum scientists were aware of the tremendous power produced by an explosion. In fact, several attempts were made to utilize this power for useful purposes. One early experimenter tried to use gunpowder for fuel in a crude motor, and another tried hydrogen gas. The ideas were already formulated in the minds of the early inventors, but these ideas could not be effectively put into practice until the discovery of petroleum and the subsequent production of liquid and gaseous fuels. All aircraft engines use either liquid fuels, such as gasoline or Diesel fuel, or gaseous fuels. The engines of the Graf Zeppelin could be operated either on liquid fuel or on Blau gas drawn from large containers located in the hull. All airplane engines are operated on liquid fuels. However, before the fuel can be used by the engine, it must be changed from a liquid to a gas. This is accomplished by means of a *carburetor.* The carburetor meters the correct quantity of fuel to be supplied to the engine, atomizes it in much the same way as an atomizer sprays perfume, and mixes the fuel with the air. The carburetor must supply the correct amounts of fuel and air regardless of the speed and load at which the engine is operating. Elementary principles of carburetion involve basic laws of physics, which are illustrated by the following experiments.

Laboratory Exercise 7. Fill a large flask half full of water and stopper it with a one-hole rubber stopper. Insert a glass tube in the stopper so that the lower end of the tube extends beneath the surface of the water. Let some student try to blow the stopper out of the flask by blowing in or into the tube and increasing the air pressure above the water. Be sure that the stopper is tight in the flask. Explain the results.

Laboratory Exercise 8. Bring an atomizer to class and demonstrate to the class how it works. The same principle is involved in the atomization of fuel by a carburetor.

Laboratory Exercise 9. If a glass working model of a lift pump is available, show how a decrease of pressure above a liquid causes the liquid to rise in the tube because of the pressure of the atmosphere. If a model pump is not available, one can be made from a large-diameter glass tube and a piston made from a stick with a wad of cloth tied on one end of it. Make the wad of cloth large enough so that it will fit snugly in the tube.

The simple float-type carburetor. The float-type carburetor is made up of four main parts: (1) the float chamber, (2) the fuel-metering jet, (3) the throttle valve, and (4) the venturi tube. Gasoline enters the float chamber through the fuel-supply line. A float, which is usually made in the form of a hollow metal ball, is attached to an arm which pivots about the other end in an up-and-down movement. A pointed rod, called the *needle valve,* is also moved up and down by the arm of the float. The needle valve controls the opening that connects the fuel line with the carburetor. When the float is raised to its normal level position, the point of the needle valve closes the fuel-supply opening and completely shuts off the flow of gasoline from the tank. As the float moves down, the needle valve moves down and allows more gasoline to flow into the float chamber. Thus the fuel level in the float chamber is regulated and remains at an almost constant level. From the float chamber a short pipe leads to a jet, which is located in the middle of the venturi tube. The discharge nozzle is at the top of the jet and is located in the region of highest velocity of the venturi tube, slightly above the fuel level in order to prevent overflowing.

The venturi tube is so shaped that it increases the velocity of the air as the air passes the discharge nozzle. As the air rushes through the venturi, it creates a lower pressure than that in the float chamber, and the gasoline is drawn out in the form of a fine spray through small openings in the nozzle. Most of the gasoline spray vaporizes immediately, while the rest is not vaporized until it encounters the hot cylinders.

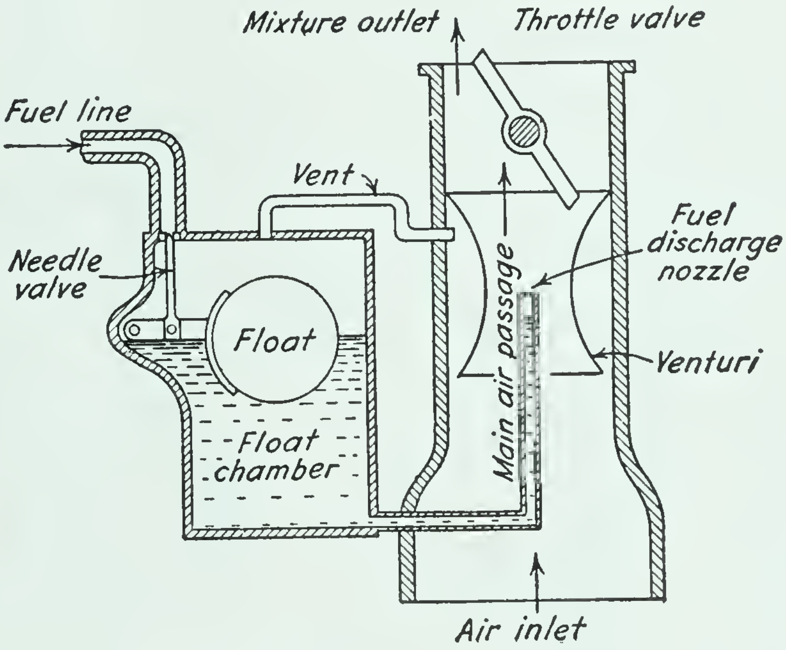


Fig. 141. Simple float carburetor

As the piston moves down in the cylinder on the intake stroke, a partial vacuum is formed in the cylinder and the intake manifold, causing air to be forced into the carburetor through the air inlet. The intake manifold is the tube which connects the carburetor to the cylinder. As the air rushes through the venturi tube, gasoline is forced from the discharge nozzle in the form of a fine spray and carried along to the cylinder in the form of spray and gasoline vapor. As gasoline is drawn from the discharge nozzle, the fuel level drops in the float chamber. Since the needle valve opens automatically as the float follows the fuel level down, more gasoline then flows into the float chamber, and the needle valve closes as the fuel level rises. Thus a supply of fuel is maintained in the carburetor. Fuel reaches the carburetor from the fuel tanks either by gravity flow or by means of fuel pumps which are geared to the engine. In airplane engines gravity flow is not satisfactory because the fuel tank changes its relative position with respect to the motor if any complex maneuver or inverted flight is attempted. In the float-type carburetor the float chamber is located in such a way that the fuel inlet to the gasoline jet is always covered with gasoline whether the ship is in a dive, roll, climb, or inverted position. The throttle in an airplane operates a throttle valve (butterfly valve) which is located above the venturi tube in the passage leading to the cylinders. The throttle regulates the amount of mixture that reaches the cylinders. In this way it controls the power of the engine since the speed of the engine depends upon the quantity of gasoline vapor and air burned in the cylinder. Modern aircraft float-type carburetors are more complex than the one just described, but they work on the same general principle.

It is necessary that an airplane engine operate efficiently under a variety of conditions and a wide range of speeds. One of the changeable conditions depends upon the altitude at which the plane travels. The higher a plane rises above sea level, the thinner the air becomes; *i.e.* as the altitude increases, the density of the air decreases. A decrease in density means that the actual weight of air in a given volume at, say, 15,000 feet altitude is less than the weight of an equal volume of air at sea level. This signifies that there are fewer molecules of gas at high altitudes than there are at low altitudes. It is evident that the higher a plane flies, the less the amount of oxygen in a given volume of air. This fact makes it necessary for a pilot to wear an oxygen mask at high altitudes. Gasoline vapor will not burn and expand without oxygen, which is necessary to bring about combustion. At an altitude of 20,000 feet and with the carburetor adjusted for sea-level performance, the mixture from the carburetor contains about 50 per cent too much gasoline. Thus there is more gasoline present in the cylinders than can be burned with the available oxygen supply. It is necessary, therefore, that some device be used to allow a greater volume of air to enter the carburetor in proportion to the amount of gasoline or to allow less gasoline to enter the venturi tube for the same volume of air. The device used is called a *mixture control,* which, in the carburetors of the larger engines, is automatically controlled by changes in atmospheric pressure. The control is activated by an aneroid mechanism whose operating principle resembles that of the aneroid barometer which was studied in the unit on weather. (See Fig. 142.) As the airplane climbs, the air becomes less dense, allowing the metal bellows to expand. Thus, the aneroid valve point lowers and reduces the pressure in the carburetor regulator unit. This restricts the gasoline flow to the spray nozzle.

Another difficulty encountered is the plain-jet carburetor's inefficiency when the engine is idling or turning at slow speeds. The air moves so slowly through the venturi tube that an insufficient quantity of gasoline is forced into the tube from the discharge nozzle. The air inlet causes the gasoline to come up in a continuous series of very small drops. You have probably experienced this effect if you have ever bent a straw through which you were drinking. The straw will break slightly and allow air to enter. Reduced pressure in the straw will bring the liquid up in a series of drops instead of in a steady flow. In the carburetor a device called the *air-bleed jet* tends to help increase the amount of gasoline available to the cylinders at idling speeds.

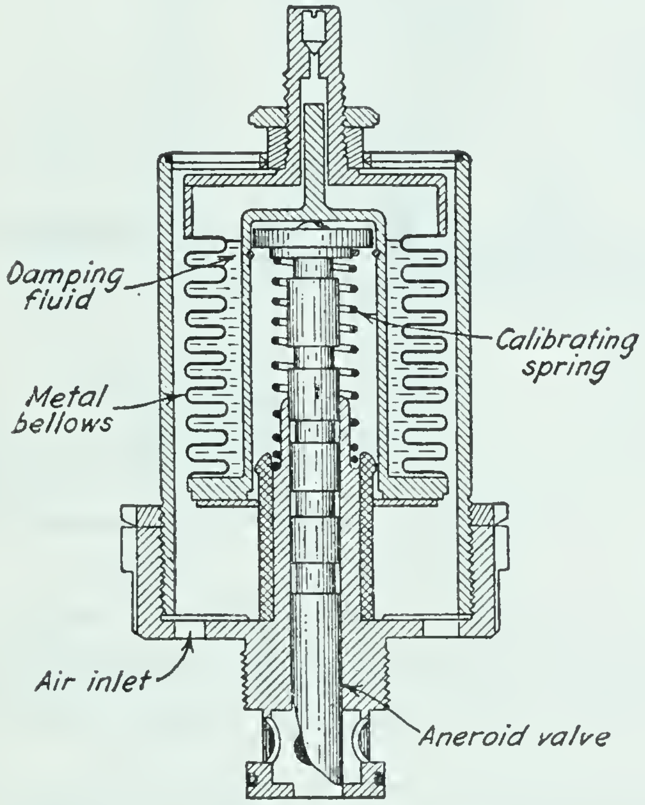


Fig. 142. Carburetor automatic altitude control

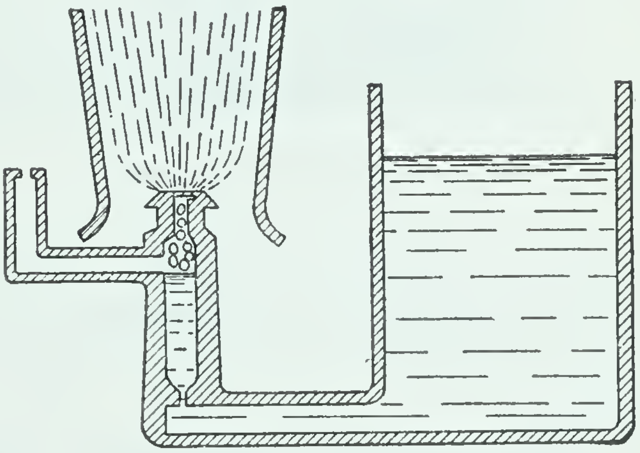


Fig. 143. Air-bleed principle

There are other devices that tend to make the airplane carburetor more efficient as well as more complex. An *accelerating well* or *accelerating pump,* operated by the throttle, gives a much-needed richer mixture if the throttle is opened quickly at low speeds. Various kinds of *economizer* systems are used that provide a lean mixture for cruising speeds and a much richer mixture for full-speed operation or when reserve power is required. Economizer systems, when in operation, tend to increase rather than decrease gasoline consumption.

The float carburetor has certain characteristics which are tending to make it obsolete in aircraft. Two of the most important are the slopping about of the fuel in the *float* chamber during complex maneuvers and the tendency for ice to form in the carburetor under certain atmospheric conditions. The ice hazard makes it necessary to equip the carburetor with a heater, which increases the weight of the engine.

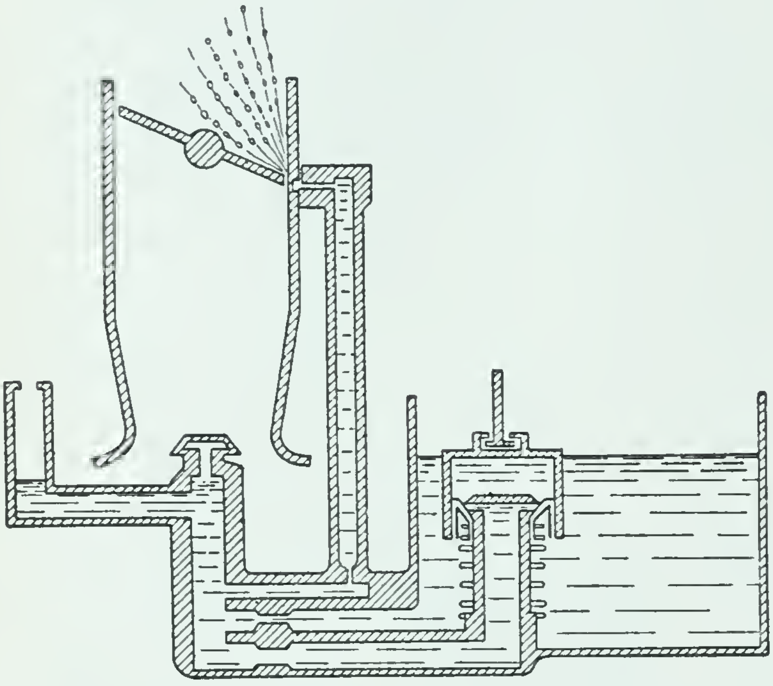


Fig. 144. Accelerating pump

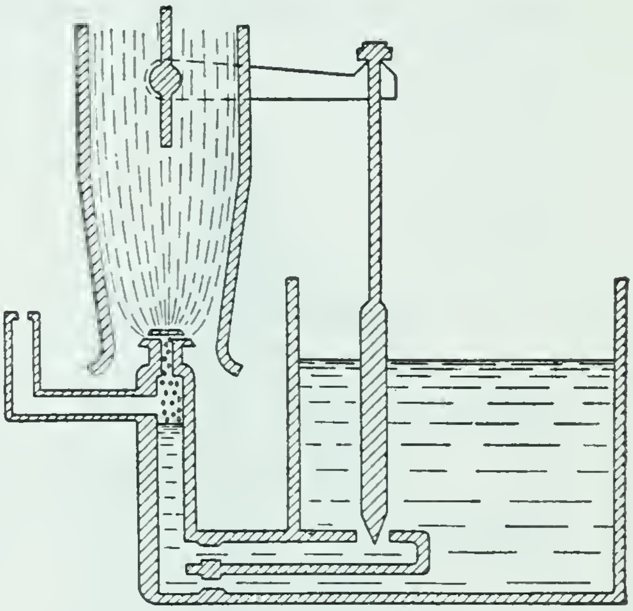


Fig. 145. Needle valve economizer

The injection carburetor. The injection-type carburetor meters the fuel through fixed openings according to the reduced pressure in the venturi tube. There are two distinct differences between the float carburetor and the injection carburetor. In the float carburetor reduced pressure in the venturi tube injects gasoline into the air stream; whereas in the injection carburetor the fuel is atomized and sprayed into the air under pressure by a pump. In the float carburetor the gasoline is sprayed into the venturi tube; whereas in the injection carburetor the gasoline is sprayed into the air beyond the throttle valve after the air has passed through the venturi. The amount of gasoline injected by the pump is dependent upon the mass of air which enters the venturi through the air inlet. An aneroid automatic altitude control (previously mentioned), sensitive to both pressure and temperature changes, automatically regulates the gasoline flow. A venturi tube is comparable to an airfoil that has been turned inside out, and its efficiency is greatly lowered if liquid fuel is sprayed into it. By comparing a diagram of a venturi with a diagram of a wing cross section, the relationship between the two can be seen readily. Since the fuel is sprayed into the venturi of a float carburetor, the injection-type carburetor is the more efficient and has a greater range of fuel metering and a greater accuracy of mixture regulation. The float carburetor, because of its disadvantages, is gradually being replaced by injection and other types of carburetors.

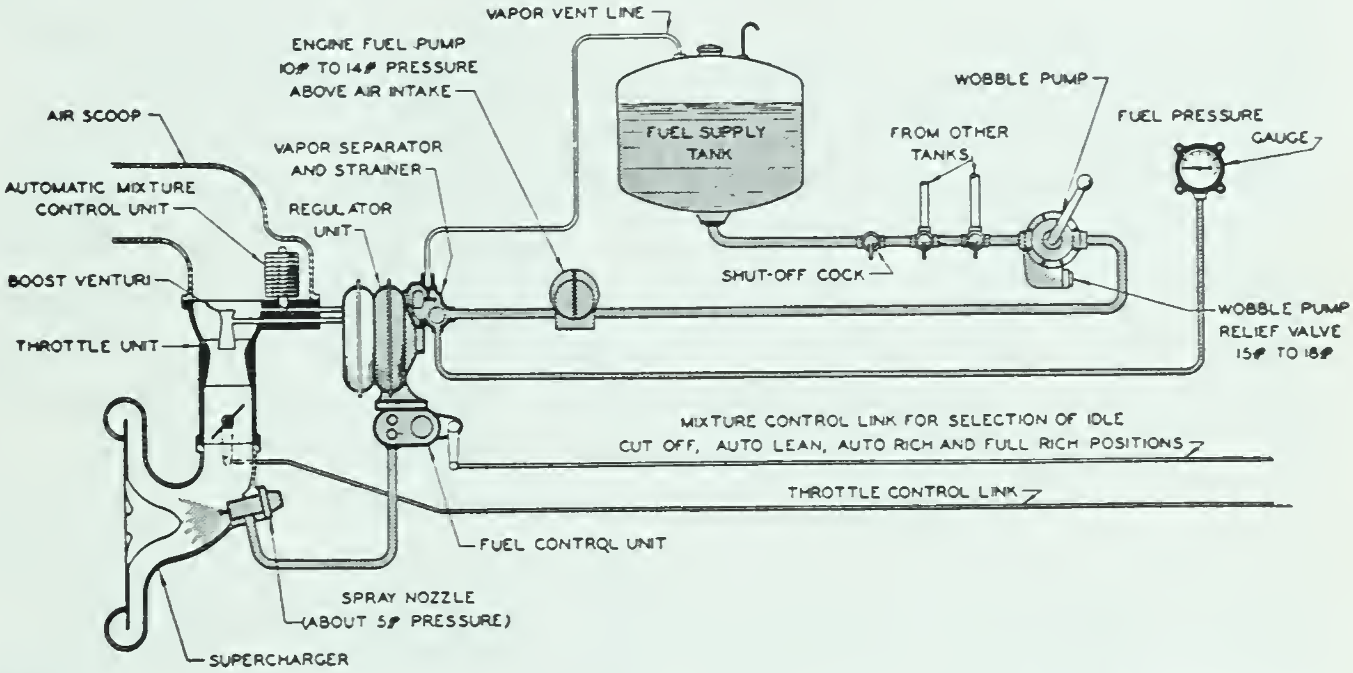

VAPOR VENT LINE
ENGINE FUEL PUMP 10# TO 14# PRESSURE ABOVE AIR INTAKE
AIR SCOOP
VAPOR SEPARATOR AND STRAINER
AUTOMATIC MIXTURE CONTROL UNIT
REGULATOR UNIT
FUEL SUPPLY TANK
WOBBLE PUMP
FROM OTHER TANKS
FUEL PRESSURE GAUGE
BOOST VENTURI
SHUT-OFF COCK
THROTTLE UNIT
WOBBLE PUMP RELIEF VALVE 15# TO 18#
MIXTURE CONTROL LINK FOR SELECTION OF IDLE CUT OFF, AUTO LEAN, AUTO RICH AND FULL RICH POSITIONS
THROTTLE CONTROL LINK
FUEL CONTROL UNIT
SPRAY NOZZLE (ABOUT 5# PRESSURE)
SUPERCHARGER

Fig. 146. Installation diagram of injection carburetor in a supercharged engine

The supercharger and its purpose. The resistance of air at high altitudes is less than it is at sea level. Therefore the power that will drive a plane at a speed of 150 miles per hour at sea level will drive it much faster at 15,000 feet and still faster at 30,000 feet with approximately the same fuel consumption, provided the airfoils are properly adjusted. The power developed by an internal-combustion machine depends on the weight of fuel burned in the cylinders during each revolution. At high altitudes the lower atmospheric pressure constitutes a problem because the reduced pressure in the cylinder cannot draw in a heavy enough charge of air-fuel mixture to maintain sea-level power and compression. At an altitude of about 20,000 feet an ordinary airplane engine develops only about one half as much power as at sea level. The airplane's maximum altitude is limited since the higher it goes, the greater the drop in power. In certain types of aircraft it is important that the plane be able to reach high altitudes. The military pursuit plane is one example, for the plane that can go the highest has a great advantage over its foes. Another example is the airliner which flies in the substratosphere, where atmospheric storms do not exist.

The answer to the problem of power loss with increase in altitude is the *supercharger.* Supercharging means that a greater quantity of charge is being forced into the engine cylinders than can be forced in by the normal atmospheric pressure at a given altitude. The supercharger compresses the less dense air at high altitudes until it has the same pressure as the air at sea level. It does not follow that with such a device there is no limit to the altitude a plane can reach. When a plane reaches such an altitude that the supercharger can no longer maintain sea level pressure, the plane is at its *critical altitude.* Supercharged airplane engines are sometimes called *altitude engines.*

The supercharger is essentially a "blower" and may be operated either by the exhaust gases or by a system of gears, but it is usually geared to the engine in such a manner that it turns from five to twelve times as fast as the engine. If the engine speed is normally 2000 r.p.m., then the supercharger might make 24,000 r.p.m.

If an engine is supercharged, certain precautions must be taken by the pilot in taking off and in flying at low altitudes. The power must be applied slowly and only to the point where take-off is possible. This technique is necessary to prevent overloading of the engine cylinders. It must be remembered that the supercharger is designed to compress the air at high altitudes to the same pressure found at sea level, and if the air is already at sea-level pressure, the increased pressure from the supercharger may produce overheating and failure of the engine.

There are certain disadvantages in installing a supercharger in a plane. It increases initial cost, overhaul expense, and weight of the plane; it absorbs power from the engine and gives the pilot an added responsibility.

Ice formation in the carburetor. By now it should be realized that the carburetor is the heart of the gasoline engine and supplies the "life blood" to the cylinders. In animals, if the heart becomes weak and does not pump enough blood, the animal becomes weak and dies. In the airplane, there is a similar situation.

In the unit on meteorology certain principles applicable to air and moisture were developed: (1) The air always contains some water vapor. (2) The cooler the air becomes, the less vapor it will hold. (3) If the air is cooled below its dew point, the moisture in it will condense out on any available cool object with which it comes in contact. In addition one other principle must be understood. As a liquid evaporates, the molecules move farther apart and, in order to do so, must move fast enough to break away from the pull of the neighboring molecules. It has already been pointed out that before a molecule can move faster it must in some way absorb heat from its surroundings. Since the gasoline in the carburetor is not evaporated over a flame or by applied heat, it must evaporate by absorbing heat from surrounding materials. This principle can best be illustrated by some simple experiments.

Laboratory Exercise 10. Wrap the bulb of a thermometer with cotton and tie it securely in place. Dip the cotton-wrapped end in water and then hold the thermometer in front of an electric fan. Record the initial temperature and the lowest temperature observed. Repeat the experiment using in turn gasoline, carbon tetrachloride, and ether. Explain the results. CAUTION: Do not use "leaded" gasoline. Locate the fan so that fumes will be blown out of the window.

Laboratory Exercise 11. Place a drop of ether or carbon tetrachloride on the wrist and fan it gently. Explain what happens and how it happens.

Laboratory Exercise 12. Secure a large flat cork and make a small hole in it. Fill this hole with water. Place a watch glass over the water-filled hole, and fill the watch glass with ether. Fan the surface of the ether rapidly until the ether has all evaporated. Then pick up the watch glass. Explain results.

The principle brought out by these experiments and the three principles previously mentioned must all be considered in connection with the formation of ice in airplane carburetors.

The evaporation of gasoline in the venturi withdraws heat from the air and the adjacent metal parts of the carburetor. As a result of this evaporation the air in the venturi may be cooled by as much as 70 degrees, and seldom is the cooling less than 30 degrees. The wider the throttle is opened, the greater is the drop in temperature. The moisture in the air freezes and is deposited principally on the venturi or throttle with which it comes in contact. Ice is more likely to form when the relative humidity is about 60 per cent and the temperature is between 50° and 60° F. It is possible for ice in the carburetor to block the passageway to the cylinders by locking the throttle valve or to pile up and block the throttle passage so that insufficient air reaches the engine. There is also a possibility that pieces of ice may break loose from the carburetor and damage the blades of the supercharger if the plane is equipped with one.

If an engine is equipped with a kind of carburetor that is subject to icing, there is usually a carburetor heater attached with which the ice can be thawed. If the power drops steadily when the throttle is set at cruising speed, it indicates that ice may be forming in the carburetor, and the heater should be turned on. The injection carburetor is to a certain extent free from ice formation caused by vaporizing of the fuel. In this carburetor the fuel is injected beyond the throttle, and as a result the mixture does not strike any obstructions such as the venturi and throttle.

Another source of ice in the carburetor is atmospheric ice in the form of snow, sleet, and similar forms. To prevent this form of ice from getting into the carburetor it is necessary to obtain the air in such a manner that ice cannot get in. This is done by using a special air inlet.

Airplane fuels. A *fuel* is a substance which, when combined with the oxygen of the air, will burn and produce heat. Hydrogen and carbon, alone or in various combinations, produce large quantities of heat when burned and are constituents of our most important fuels. Liquid fuels are in many respects the ideal fuels for use in internal-combustion engines. For convenience, liquid fuels are classified as either *nonvolatile* or *volatile*. The former are the heavy oils used in Diesel-type engines. The volatile class includes those fuels which are commonly used with a carburetor and are carried into the engine cylinder in a vaporized or partially vaporized state mixed with the proper proportion of air. Gasoline has many advantages over other liquid fuels and, therefore, is used almost exclusively in aircraft engines. It can be produced cheaply and is available in large quantities.

To determine their fitness for specific uses as a fuel, aviation gasolines are subjected to laboratory tests. The most important of these, from an engine standpoint, are: (1) volatility, (2) vapor pressure, (3) knock value, and (4) purity.

Volatility is defined as the vapor-forming tendency of a fuel at various temperatures. Blends of gasolines are made in the blending operation in such a way that a straight chain of boiling points is obtained. The gasolines which are the most volatile evaporate at the lowest temperatures, and those that are least volatile evaporate at the highest temperatures. The most volatile gasoline in a blend should vaporize sufficiently to start a cold engine.

Laboratory Exercise 13. Make a mixture of water and alcohol and place the mixture in a distilling flask. Cork the flask with a stopper containing a thermometer. Do not allow the thermometer bulb to enter the liquid. (See Fig. 147.) Evaporate the liquid over a burner and watch the temperature. If a sudden rise in temperature should occur during the boiling process, record it, and collect the rest of the liquid in another container. Compare the volumes of liquid in the two containers with the original volumes of alcohol and water used. Explain results.

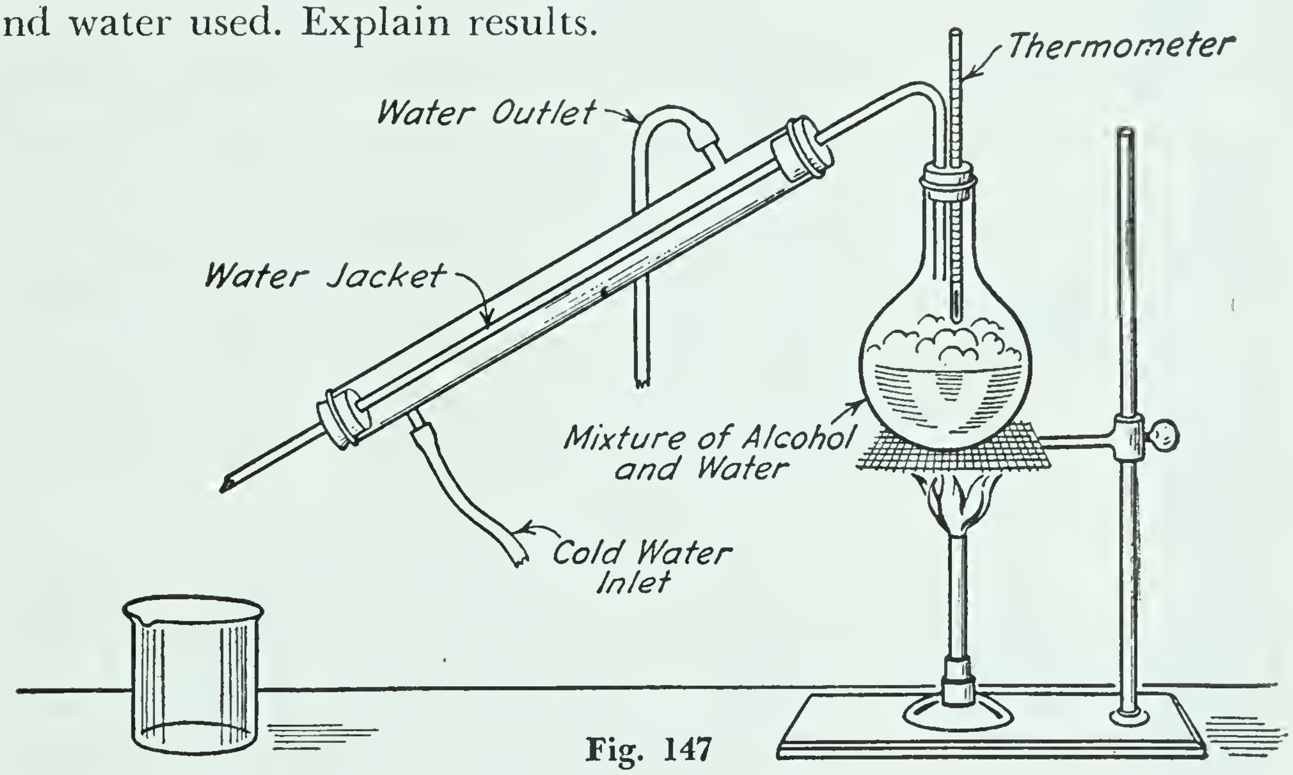


Fig. 147

The volatility of a gasoline blend may be determined by a *fractional distillation* test. If a gasoline mixture is evaporated from a flask, it is possible with a thermometer to detect a rise in the boiling temperature as the gasoline boils away. A certain fraction will be distilled at one temperature, another portion at a higher temperature, and so on until the least volatile of the gasoline is distilled. Caution: *This should never be attempted except in a specially equipped laboratory.* Why?

To limit the amount of highly volatile unstable blends which tend to create vapor lock (to be discussed later) losses in distillation of the sample tested are limited to approximately 2 per cent. In other words, the material left in the distilling flask and the amount of fuel recovered by distillation should equal 98 per cent of the original supply after completion of the distilling process.

The specifications of lower-grade automobile fuels are not held within the close limits required by aviation engines. Automobile gasoline usually contains a considerable amount of "cracked" gasoline (formed by breaking down heavy, less volatile petroleum compounds) which sometimes forms excessive gum deposits. Such gasoline can be used in automobile engines if chemicals are added to the gasoline to prevent gum formations. Cracked gasoline is generally excluded as an aviation fuel because the high cylinder temperatures, especially in those engines which are supercharged, tend to destroy the effectiveness of the chemicals that prevent gum formation.

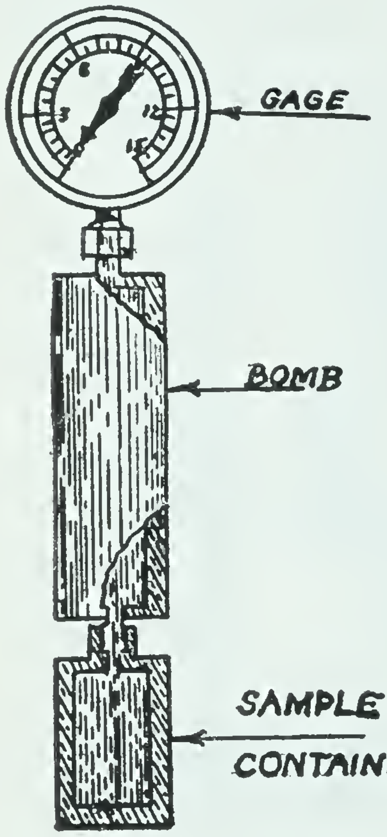


Fig. 148. Vapor-pressure test apparatus. The gasoline to be tested is placed in the sample container and the fumes allowed to expand into the bomb, thus exerting pressure on the gage.

Obviously, when a fuel is made up of a number of materials vaporizing at different temperatures, some of the more volatile parts of the fuel, that is, parts which will vaporize at low temperatures, may vaporize before they reach the carburetor or before they have passed through the carburetor jets. Since the jets are designed to measure and pass liquid but not vapor, improper mixing results.

As a check on the tendency of a part of the fuel to vaporize too readily, the *vapor pressure* or tendency to volatilize is also measured and controlled by specification. This measurement is made at a temperature of 100° F. in an apparatus in which the actual pressure of the fuel is shown on a gage. This pressure usually is specified to be less than seven pounds per square inch.

Vapor lock is a condition that occurs when the fuel line develops vapor bubbles in it. If the fuel line passes too close to the exhaust manifold or other hot portions of the engine, highly volatile gasolines vaporize and expand to about 200 times their normal liquid volume. In view of this fact, it readily may be appreciated that with the reduction of liquid, the carburetor jets will supply insufficient fuel to run the engine.

Carburetor icing is also related to volatility. When the fuel changes from the liquid to the vapor state, it must absorb heat from its surroundings to accomplish this change. The more volatile the fuel the more rapid will be the heat absorption and consequently the greater the tendency for ice formation.

Detonation is a rapid increase in the rate of burning of the fuel in the cylinder. In normal combustion, without detonation, the flame of combustion measured from the spark plug travels across the combustion chamber at the rate of 25 to 75 feet per second. When detonation occurs, the rate of movement of the flame is increased to approximately 4000 or 5000 feet per second and frequently crosses the combustion chamber several times during one firing. This tremendous increase in the speed of burning is accompanied by extremely high local temperatures and tremendous increases in pressure. The tremendously increased pressure of detonation, exerted in such a short space of time, gives a heavy shock load to the walls of the combustion chamber and to the piston head. Since the piston cannot move rapidly enough to escape the full force of the blow, this shock to the combustion chamber constitutes a "knock" in the engine, such as is sometimes heard in automobile engines. In the automobile engine the knock is usually audible, but it generally is necessary to depend upon cylinder-head temperature rather than the ear to detect knocks in an aircraft engine, except in the smaller aircraft engines in which the "ping" is distinctly audible when detonation is taking place. An increase in cylinder-head temperature is measurable when detonation occurs. Fuels with high antiknock qualities can be selected and subsequently treated with very small quantities of a compound known as *tetraethyl lead* which slows down the rate of burning of the fuel. Tetraethyl lead is undesirable in airplane fuels because of its corrosive action and is, therefore, avoided as far as possible.

Gasoline as received from the vender should be free from water and sediment, and every care should be taken in its storage and handling to prevent the introduction of water or any other substance into it. This prohibition applies also to air, which should not be introduced into the gasoline by means of leaking delivery lines to pumps or by exposing gasoline stored in small tanks or drums to violent temperature changes, such as are set up by direct exposure to sun and rain. Gasoline storage containers, unless hermetically sealed, tend to breathe out vapor when heated and breathe in air when cooled.

Gasoline as received from the vender should contain a minimum of sulphur and its compounds, which are common impurities in petroleum in the ground. Gasoline suitable for aviation should not contain gum or compounds that form gum under normal temperatures encountered in storage.

Fuel supply in the airplane. Airplane fuel supply systems can be divided into two main types: (1) gravity type, and (2) pressure-feed type.

A gravity system depends on the force of gravity to supply gasoline to the carburetor. Gravity systems are seldom used except in airplanes equipped with low-powered engines, and then only when the fuel tank can be located some distance above the carburetor. For sufficient gravity flow, the tank must be from 20 to 48 inches above the carburetor, which necessitates mounting the tank in the wing. Such an arrangement cannot be used in low-wing monoplanes or in airplanes in which the engines are mounted in the wing or on a level with it. The feed lines from the gravity tank should always slope downward to the carburetor in order that no "kinks" may exist. A kink in the fuel line is usually the place where vapor locks are most likely to occur. A filter should be installed at the junction of the fuel line with the carburetor. The filter should be cleaned and inspected regularly. Every fuel system requires a filter to separate water and sediment from the gasoline.

The *fuel-pump* system is used on the majority of aircraft engines. A fuel pump, usually gear-driven by the engine or operated by a wind-driven gear system, is inserted in the fuel line between the fuel tank and the carburetor. It pumps the fuel to the carburetor under pressure which varies with different types of carburetor. This pressure is sufficient to provide an excess of gasoline to the carburetor, and a by-pass is placed in the line so that the fuel pressure and the air pressure at the carburetor maintain a constant relationship.

The regular fuel pump does not operate unless the engine is running. As a result of this fact a hand pump must be installed to "prime" the engine for starting. Gasoline may be pumped into the intake manifold, where the most volatile portion vaporizes sufficiently to provide fuel for the first few explosions in the cylinders. A piston-type pump is usually used for this purpose and is hand operated in smaller planes. In higher-powered engines which require large fuel flows, the auxiliary pump may be driven by an electric motor or by a hydraulic system. The auxiliary pump is also essential for emergency use should a failure occur in the engine-driven pump.

A *wobble pump* is utilized to prime the carburetor and, in some instances, to transfer gasoline from one tank to another in order to preserve the balance of the plane. A working diagram of a wobble pump is shown in Figure 149. When the handle attached to the central blade is operated, the negative pressure created on whichever side is pulled upward lifts the lower flapper, allowing the fuel to flow in behind it. As the handle is moved in the opposite direction, the lower flapper closes, preventing the fuel from escaping back into the line and causing it to flow through the passage shown in the wobble body as indicated by the arrows.

The fuel is then forced through the upper flapper on the opposite side by the upward movement of the opposite end of the wobble blade, thence to the carburetor. The cycle is repeated each time the handle is moved in either direction. The capacity of the wobble pump varies with the volume of fuel required to keep the carburetors functioning at the required fuel pressure.

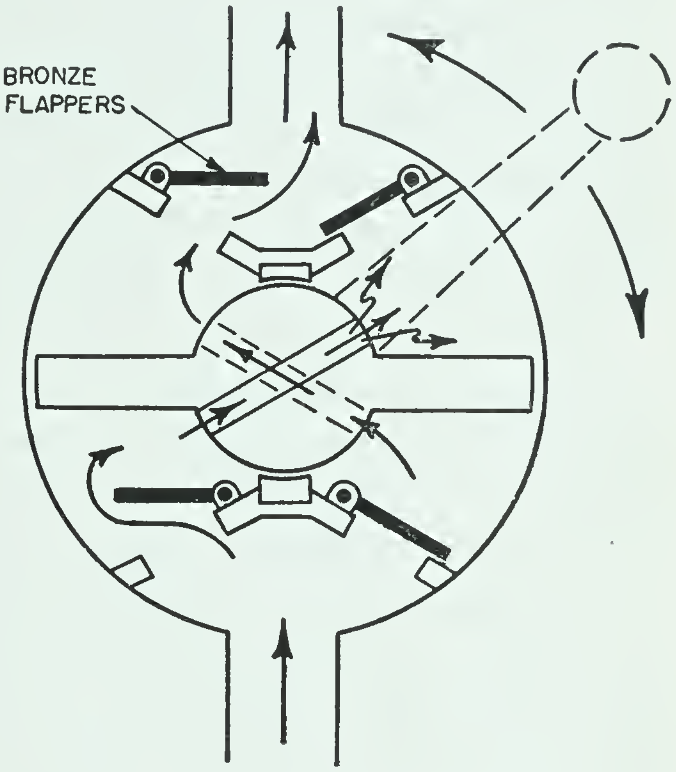


Fig. 149. Wobble pump

Exercise 14. Trace the gasoline from the fuel tank to the cylinder of an airplane engine, listing all parts through which it passes.

Exercise 15. Discuss possible causes for excess gasoline consumption in an airplane engine.

Exercise 16.

a. What is the probable cause of black smoke and dark-red flame issuing from the exhaust stacks of an airplane engine?

b. What is the probable cause of long light-blue or yellow flame?

Problem 4. How is it possible for the spark plug to ignite the fuel in the cylinder?

It has already been mentioned, in the study of the four-stroke cycle, that a spark ignites the fuel mixture just before the piston reaches the peak of its compression stroke. This spark must of necessity be of the magnitude of several thousand volts in order to jump the spark gap in the spark plug and to create a spark hot enough to ignite the fuel. Since a voltage of this magnitude cannot be obtained directly from an ordinary storage battery, it is essential that some means be provided for producing it. However, before the different methods of producing such a voltage can be understood, it is necessary to know something about magnetism and electricity.

The nature of magnetism. Few normal adults can be found in this country who do not know what a magnet is. If a friend is asked to describe a magnet, he will undoubtedly say it is a piece of iron or steel that attracts and will pick up other pieces of iron or steel. As far as his explanation goes it is correct, but there are many other aspects of magnetism that must be considered.

Magnets were discovered several centuries B.C., but the important discoveries about magnetism that make present-day ignition systems possible have occurred within the last 150 years.

The two ends of a magnet, called *poles,* are the points at which the magnetism appears to be concentrated. These poles or points of concentration can be determined by placing a sheet of paper over a bar magnet and sprinkling iron filings generously on the paper. When the paper is tapped gently with the end of a pencil, the filings rearrange themselves, concentrating at the poles more than at any other point.

Closer observation of the sheet of paper will disclose that the iron filings not concentrated at the magnetic poles arrange themselves about the magnet along curved lines that seem to stretch from one pole to the other. These lines serve to locate and map the *magnetic field* of the magnet. This magnetic field, invisible if iron filings are not used, is called the *field of force* of the magnet.

The two poles of a magnet are called the north-seeking or *N* pole and the south-seeking or *S* pole. If a magnet is suspended horizontally by a thread so that it is free to turn, it will rotate and finally come to rest in a north-and-south direction with the *N* pole pointing in the general direction of the geographic north pole of the earth. This principle of a pivoted magnet is used in the magnetic compass, which indicates direction. A magnet always tries to line itself up so that it is tangent to the lines of force of a magnetic field. The earth itself acts as a huge magnet and is surrounded by a field of force. A small magnetic compass may be used to determine the direction of the field about a permanent bar magnet.

Laboratory Exercise 17. Place a bar magnet on the table and place a small magnetic compass at one pole. Note the direction the compass needle points. Move the compass in a semicircle about the magnet with the magnet as the diameter of the circle. Plot the direction the compass needle points at intervals on the semicircle. Repeat, using an arc that extends farther, laterally, from the magnet.

The lines of force of a magnet are considered as emanating from the *N* pole and terminating at the *S* pole. The field of force from the *N* pole of one magnet repels the field of force of another *N* pole. As a result of this, two *N* poles repel each other and, also, for the same reason two *S* poles repel each other. On the other hand, an *N* pole and an *S* pole are attracted to each other.

Laboratory Exercise 18. Cover a U-shaped magnet with a sheet of paper and sprinkle iron filings on it in the manner previously described. Sketch the magnetic field showing the lines of force and concentrations of magnetism. Now place a piece of scrap iron across the poles of the magnet and again sketch the magnetic field. Explain.

In nature all things take the path of least resistance. Just as a flash of lightning is attracted to and flows through a lightning rod in preference to air so will the lines of force of a magnet travel through iron in preference to air. It will be necessary to recall this fact later in the study of the airplane magneto.

The nature of electricity. Electricity, as commonly used, is recognized as energy that flows along wires and operates refrigerators, electric stoves, light bulbs, and numerous other appliances. With this information, the ordinary layman ceases to concern himself about electricity — what it is or where it comes from. Before the operating principles of the airplane ignition system can be understood, it is necessary to gain some understanding of the answers to these questions.

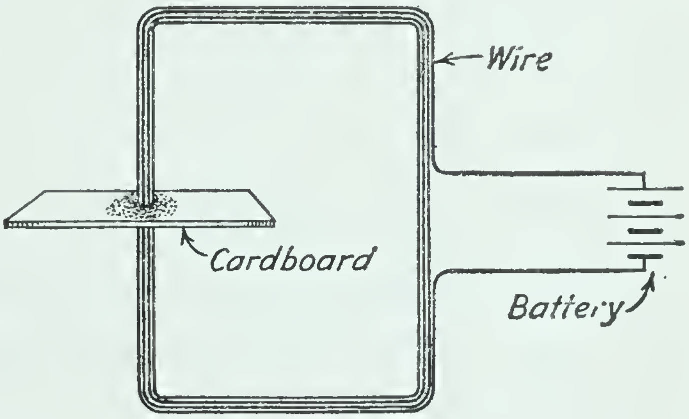


Fig. 150

One of the most important discoveries in the last two centuries was the discovery, by Oersted, in 1819, of the relationship between magnetism and electricity. He discovered that when an electric current passes along a conductor, the conductor is surrounded by a magnetic field. The lines of magnetic force about the conductor lie in concentric circles in planes perpendicular to the conductor.

Laboratory Exercise 19. Form a rectangular loop of from 10 to 20 turns of No. 18 copper wire (insulated) and support it vertically on its shorter side. Cut a slit in a square piece of cardboard, and cut a hole in the middle large enough to fit the loop of wire (Fig. 150). Send current through the loop from dry cells (or storage battery) and sprinkle iron filings on the cardboard. Sketch the arrangement of the filings. If a small compass is available, place it at different points about the wire and determine the direction of the field. The direction of the field will be the direction in which the *N* pole of the compass needle points.

Furthermore, a circular loop of wire, carrying a current, will arrange itself in a magnetic field as if one face of the coil were an *N* pole and the other an *S* pole. If several coils of wire are connected together in a spiral form (similar to a door spring), this magnetic effect can be readily seen.

Laboratory Exercise 20. Thread a coil of wire in spiral form through holes punched in a piece of cardboard. Pass a current of electricity through the coil, and sprinkle iron filings on the cardboard. Sketch the magnetic field. Note: If the coils are spaced too far apart, the desired results will be inadequate.

A coil arranged as a spiral is called a *helix;* when carrying an electric current, it has a magnetic field equivalent to that of a bar magnet. If a bar of soft iron is inserted into the spiral, the magnetic effect of the coil is greatly increased.

Another discovery, equally as important as that of Oersted, was the method of obtaining a current of electricity from a magnetic field. It was found that, if a moving conductor cuts through a magnetic field, a current is set up in the conductor, provided it is a part of a closed circuit, and provided its motion is not parallel to the field. The same effect is produced if the magnetic field moves past the conductor. In other words, the relative motion of conductor and magnetic field is the necessary factor for the production of an electric current in the conductor.

Laboratory Exercise 21. Construct a coil of from 50 to 100 turns of small, insulated copper wire, and connect the coil in series with a galvanometer (Fig. 151). Thrust one pole of a bar magnet into the coil and watch for motion of the galvanometer indicator. Withdraw the magnet from the coil and compare the results with those first obtained. Hold the magnet stationary in the coil and note results.

Now reverse the polarity of the magnet and repeat. When this is finished, make (or obtain) an electromagnet and repeat the experiment. Finally, place the electromagnet in the coil and make and break the circuit of which the electromagnet is a part. What conclusions can be drawn?

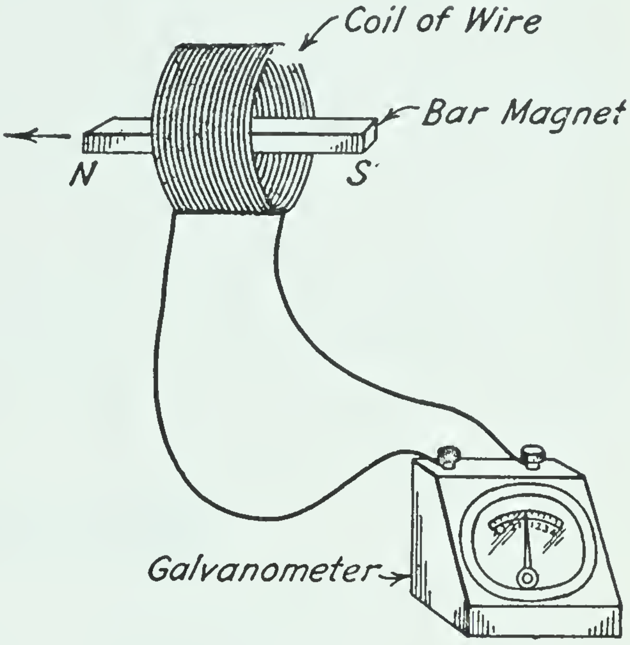


Fig. 151

This effect of the relative motion of a conductor and magnetic field is the principle underlying the electrical generator which provides current for everyday use. The direction in which the magnetic field is cut determines the direction in which the induced current will flow. As seen from the experiment just completed, if the magnet moves in one direction, a current flows through the galvanometer. If the direction of motion or the polarity of the magnet reverses, the direction of the current reverses. Therefore, a periodic reversal of the magntic field or of the direction of relative motion of magnet and conductor produces an *alternating current,* one which reverses its direction of flow periodically. The airplane magneto is essentially an alternating current generator.

The transformer. The generator in an airplane magneto does not generate as high a voltage as is required by the spark plugs. This higher voltage is developed from the low voltage of the generator by means of a *transformer.*

The transformer, in principle, is composed of a core of iron about which are wrapped two coils of wire as Figure 152 illustrates. One of the coils contains a greater number of turns of wire than does the other; one coil is called the primary and the other the secondary of the transformer. If the purpose of the transformer is to produce a high-voltage current, the low-voltage current enters the transformer through the coil with the smaller number of turns. This coil then becomes the primary, and the other coil becomes the secondary. A transformer of this type, called a *step-up transformer,* is the only type that need be considered in connection with the airplane ignition system.

When a low voltage alternating current passes through the primary winding of the step-up transformer, a magnetic field is set up in the iron core. As the current alternates and flows in the opposite direction, the magnetic field collapses and builds up in the opposite direction. The effect, then, of an alternating current is to set up in the iron core a magnetic field that reverses itself every time the current reverses in the primary coil, rising to maximum strength, reducing to zero, and then rising to maximum strength in the opposite direction. The same lines of force that pass through the primary windings also pass through the secondary windings by the continuous path provided by the iron core. When the current surges in one direction through the primary, lines of force cut the secondary and produce (induce) a current in the secondary. As the current reverses in the primary, it also reverses in the secondary, which produces an alternating current in the secondary coil.

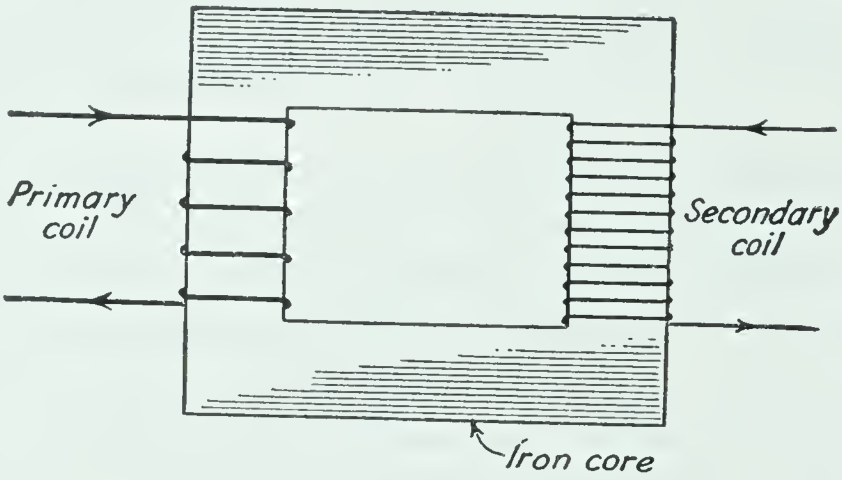


Fig. 152. Simple diagram of a step-up transformer

In order that a comparatively low voltage in the primary circuit be changed to a high voltage in the secondary circuit, the secondary coil must contain many more turns than the primary contains. The relationship between the two is given by the following formula.

$$\frac{\text{Number of volts in secondary}}{\text{Number of volts in primary}} = \frac{\text{Number of turns in secondary}}{\text{Number of turns in primary}}$$

This relationship can be readily illustrated. Assume that the number of turns on the secondary is 2000 and the number of turns on the primary is 20. How many volts will be induced in the secondary with 10 volts flowing in the primary?

$$\frac{\text{Number of volts in secondary}}{10} = \frac{2000}{20}$$

$$\text{Number of volts in secondary} = \frac{2000 \times 10}{20} = 1000 \text{ volts}$$

With a rise in voltage in the secondary there is a corresponding decrease in current. The primary has low voltage and high current, and the secondary has high voltage and low current.

Exercise 22.

a. The primary of a transformer has 25 turns. The secondary has 875 turns. What voltage will be produced in the secondary if 6 volts are applied to the primary?

b. Twenty volts in the primary of a transformer are built up to 10,000 volts in the secondary. If the secondary has 1500 turns, how many turns are there in the primary?

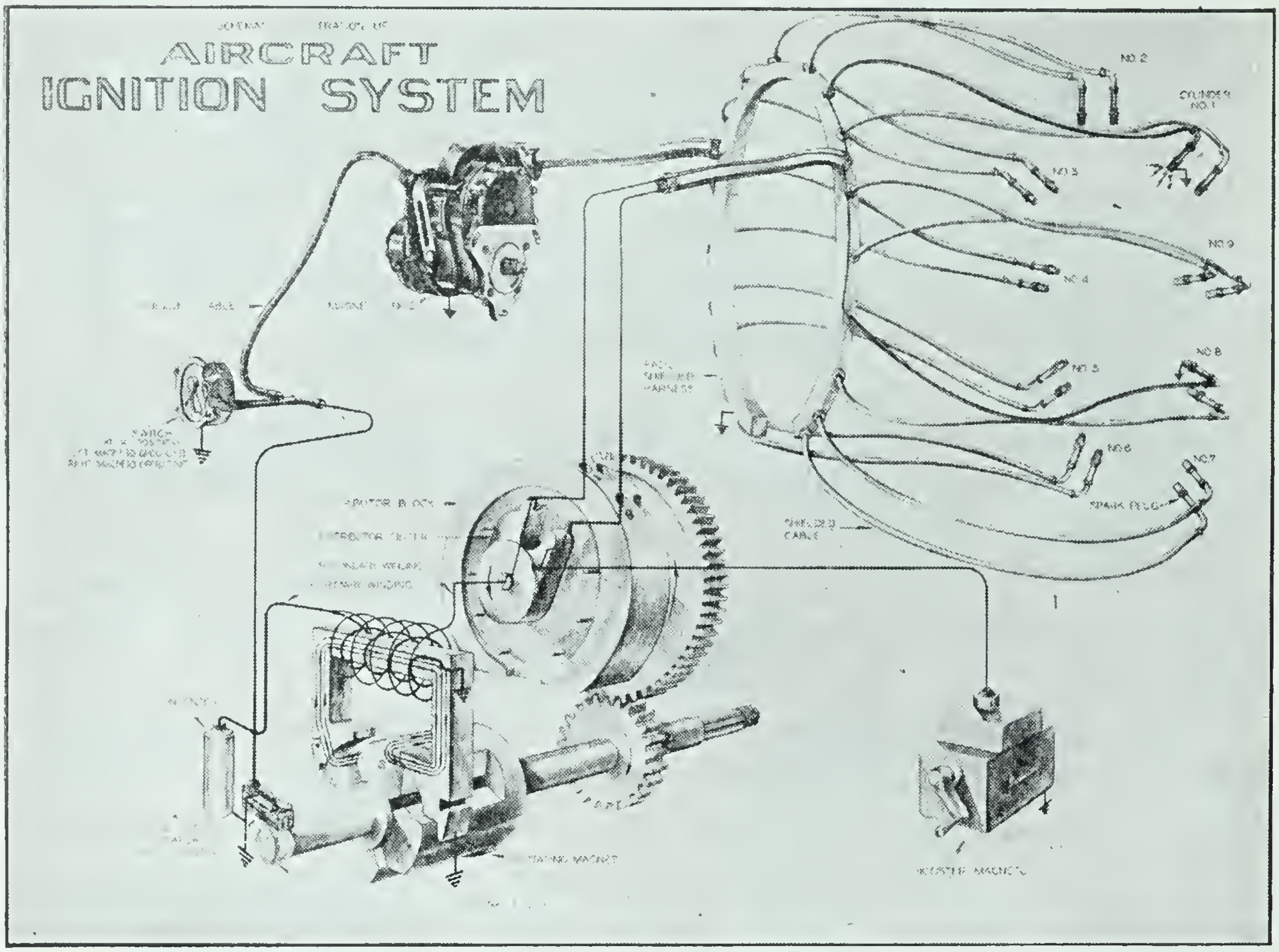
The airplane magneto. The *airplane magneto* is essentially a combination of an alternating current generator and a transformer. The purpose of the magneto is to provide the high voltage spark for the spark plug. The accompanying diagram shows the structure of the airplane magneto and the way in which it is connected to the distributor and to the circuit breaker.

Two magnetos are used in modern planes, and while both are shown in the diagram (Fig. 153), only one is shown in detail.

In the diagram, the rotating magnet creates a changing magnetic field in the iron core. This changing magnetic field induces an alternating current in the primary winding, which in turn induces a higher voltage in the secondary winding. This high-voltage current is then sent to the spark plugs.

It is easy to imagine what would happen if the high-voltage electricity were not controlled in some way. A spark plug would be likely to fire at any stage of the four-stroke cycle instead of at the one instant when the spark is needed. To avoid this electrical confusion, a device called the *distributor* is located between the magneto and the spark plugs. The purpose of the distributor is to direct the electrical "traffic." In other words, it sends a high-voltage current to each spark plug at just the right instant, so that the plug fires shortly before the respective piston is at the peak of its compression stroke.

In order that the voltage in the secondary may be at a maximum at the time it is needed at a spark plug, a *contact breaker* assembly (Fig. 154) is installed in the primary circuit. The contact breaker



Courtesy Bendix Aviation Corporation

Fig. 153. Magneto ignition system and radio shielding

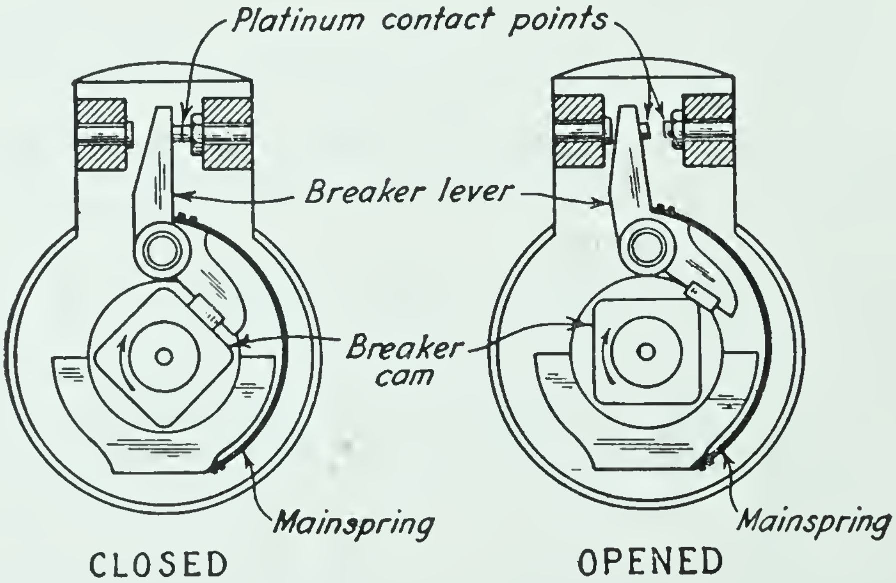


Fig. 154. A contact breaker in closed and opened positions

breaks the primary circuit much as a wall switch breaks the electrical circuit to a light bulb. If the primary circuit is suddenly broken, the magnetic field through the secondary collapses very rapidly, which greatly increases the voltage induced in the secondary. The contact breaker insures a high voltage to the spark plug at the proper time in relation to piston travel.

The magneto, distributor, and contact breaker are all geared to the engine and timed so that maximum voltage is available at the right spark plug at the proper instant.

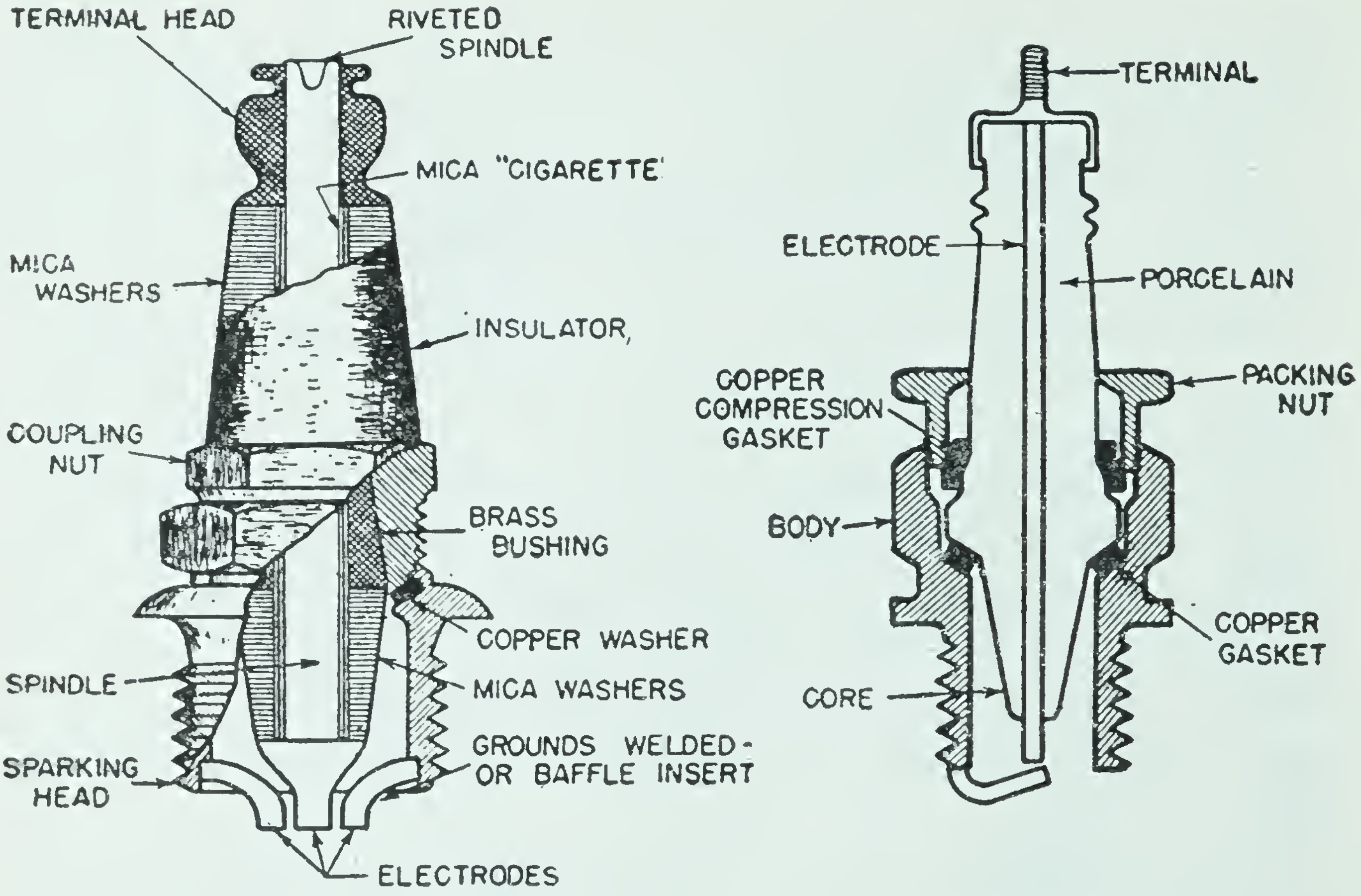
Battery ignition systems. Engines not equipped with a magneto operate by means of a *battery* ignition system. Since a battery system supplies direct current to the primary, a contact breaker must be installed to produce a change in the magnetic field. Every time the primary circuit is broken, the collapse of the magnetic field induces a high voltage in the secondary. The essential differences between the two types of ignition systems are the kind of electrical current used and the source of that current. Although some aircraft engines use battery ignition systems, the magneto system is the most extensively used.

In the event the battery charging system is out of order, or the battery is low in a ship not equipped with a generator, the pilot should bear in mind that the electrical circuit may be loaded in such a manner as to cause the ignition system to fail entirely. For instance, if a night flight of considerable length has been made with the position lights on, the battery may be very nearly discharged. There may be just enough current to operate the battery ignition system, and, when the pilot switches on the landing lights, the engine may fail entirely.

The storage battery is used in some airplanes, however, for the following purposes: (1) to start the engine, (2) for navigation and landing lights, (3) to operate the radio, and (4) for aerial photography.

Spark plugs. One of the most vital parts of the ignition system is the *spark plug.* Its function is to provide a small air gap across which the secondary current of the ignition system is forced to jump, igniting the charge compressed in the cylinder.

Spark plugs are divided into two types, porcelain and mica, according to the method of insulation. Porcelain spark plugs generally are not considered as efficient as the mica plugs for aviation use, since quick temperature changes set up internal stresses, frequently resulting in cracked insulators. They also crack quite easily from mechanical blows, causing short-circuits and failure of the plug. The mica plug is mechanically strong and withstands changes in



MICA TYPE SPARK PLUG

PORCELAIN TYPE SPARK PLUG

Fig. 155. Construction details of two types of aviation spark plugs

temperature and overheating for short periods of time without failure. The accompanying diagrams will illustrate how each is made.

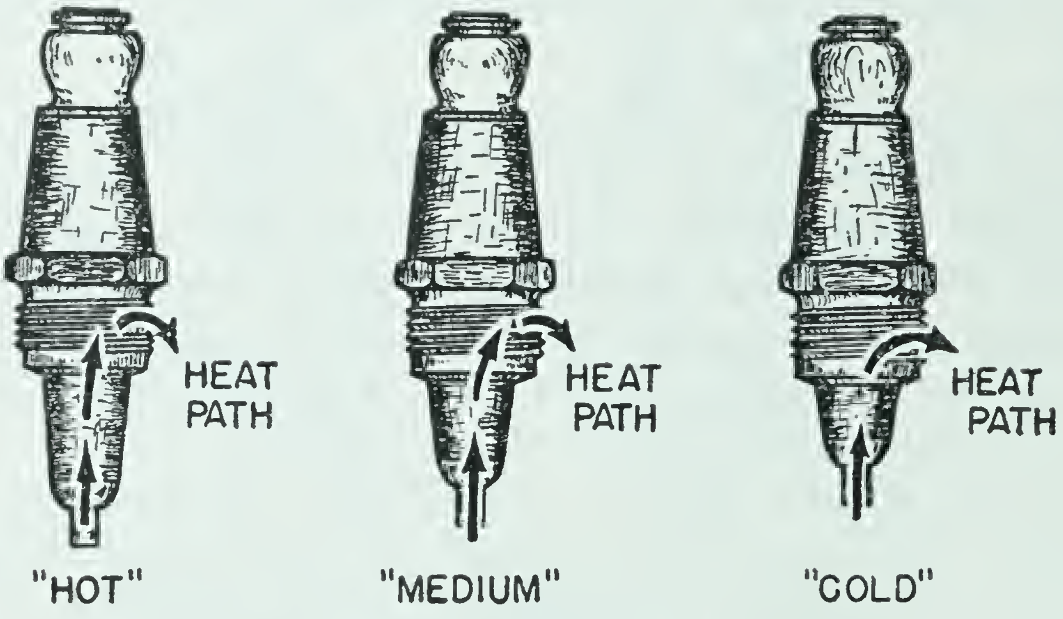
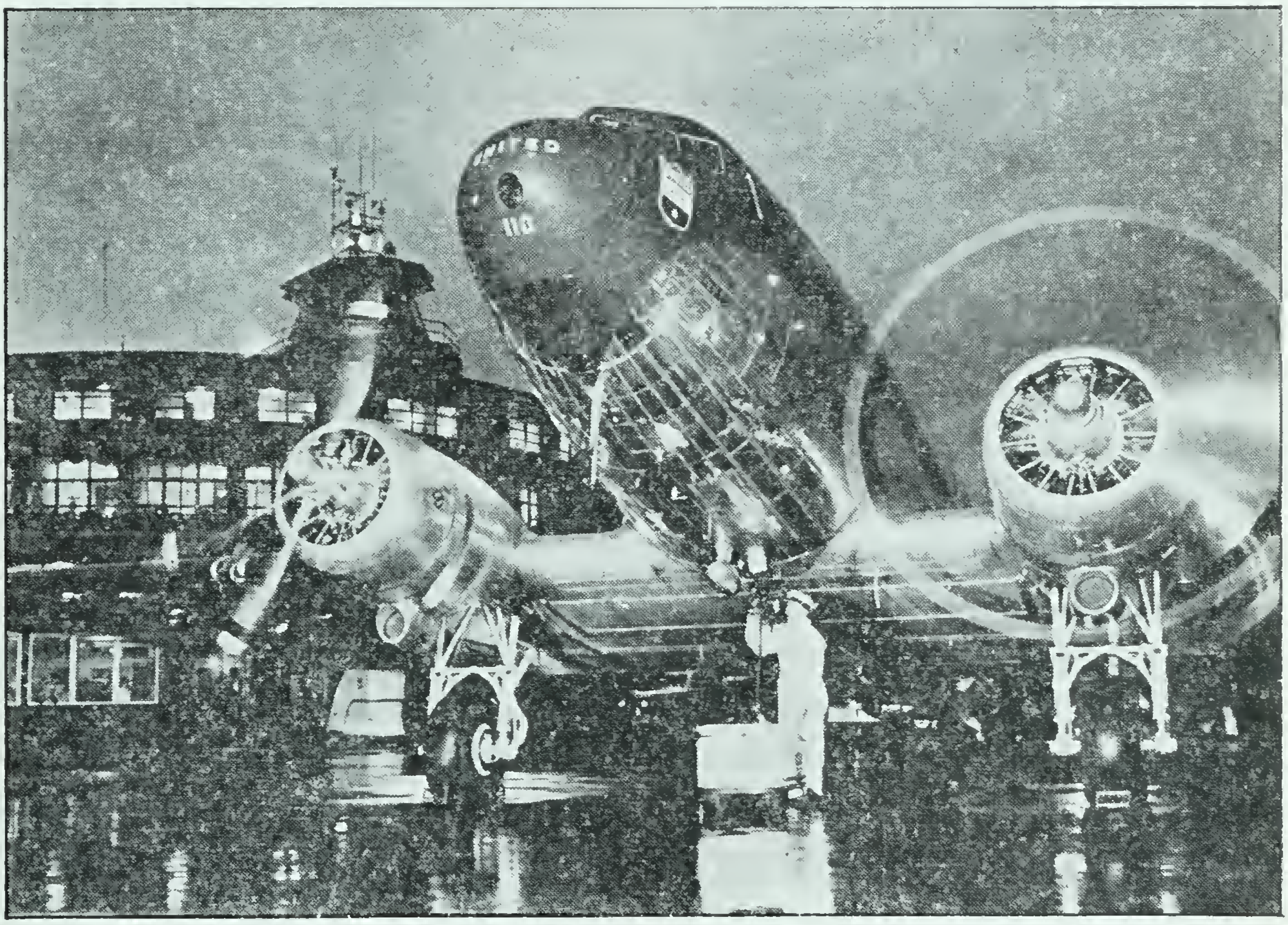


Fig. 156. Heat path in spark plugs

Spark plugs, because of their location in the combustion chamber, are exposed to very high temperatures and pressures. If the plug gets too hot, it may ignite the fuel mixture before the correct time.

This action is called *pre-ignition,* which results in a "ping" in the engine and loss of power. To prevent pre-ignition, spark plugs must be equipped with some means for cooling. Plugs are usually classed at hot, medium, or cold, depending on how efficiently the heat may be conducted away. In Figure 156 the path the heat must follow is indicated by arrows for representative types of spark plugs. The length of the heat path determines whether or not the plug is hot, cold, or medium. In some engines that develop very high cylinder temperatures, spark plugs are equipped with cooling "fins" to help transfer heat to the air.

Dual ignition. It was mentioned previously that two magnetos are used in most planes. The purpose of a double ignition system is twofold: (1) to increase the power of the engine at high speeds, and (2) to add a factor of safety. There are usually two spark plugs to each cylinder, each operated by a separate magneto and each capable of firing the fuel mixture by itself. It has been found by experiment that a high-speed engine will operate more efficiently when the fuel mixture is ignited at two different points. This type of ignition speeds



Courtesy United Air Lines

Fig. 157. Starting engines with battery cart

up the rate of burning of the fuel. Experiments show that it is possible to gain from 25 to 30 per cent in engine power at high speeds with two spark plugs per cylinder. The failure of one plug will slightly reduce the power and increase the temperature of the engine, but will not necessitate an immediate landing. In planes equipped with only one spark plug per cylinder, failure of a plug will cause a cylinder to cease firing, setting up excessive vibrations that force the plane to land.

In starting a plane equipped with dual ignition, the pilot runs the motor first on one magneto and then on the other, to insure that both are functioning normally. After this assurance is made, the engine is switched to both magnetos and run on both.

Booster ignition. It has already been pointed out that the regular ignition system does not work unless the engine is running. This arrangement does not provide the necessary current for starting the engine. To remove this deficiency, a *booster magneto* is connected to one of the engine magnetos. The booster magneto, if rotated rapidly, produces a series of high-intensity sparks. The booster magneto may be driven by a hand crank or by an engine starter.

In many large planes the engine starter is operated by a battery that is brought to the plane in a small cart and then removed after the engine is started.

Radio shielding of electric circuits. Modern long-range planes depend to a great extent on the radio for navigation and communication. It is important, therefore, that the engine should not cause static that might interfere with the radio. Whenever a high voltage jumps a spark gap, it sets up in the surrounding space what is called an electromagnetic wave, very similar to the dot-and-dash signals sent out by the wireless telegraph. This wave causes static in a radio if it is not in some way controlled. An eighteen-cylinder radial engine, if turning at the rate of 2400 r.p.m. will "broadcast" about 360 such waves per second, which will greatly interfere with radio transmission and reception.

In order to eliminate engine static, all electrical circuits are completely surrounded by metal tubes or metal shields. The magneto, contact breaker, distributor, and conductors are all shielded. All of the shielding tubes and containers are connected together and grounded to the engine about every eighteen inches. In this manner, the static is greatly decreased.

Exercise 23. Explain step by step how a high-voltage electric current is delivered to the spark plugs of an airplane engine.

Problem 5. How are airplane engines kept from becoming too hot?

Internal-combustion engines generate a great deal of heat in their cylinders to produce power. This heat is absolutely essential for the operation of the engine, but, on the other hand, it is also essential that the heat be controlled. The temperature in the combustion chambers of airplane engines may be as high as 4000° to 4500° F., nearly twice as high as the melting temperature of the metal structure. At very high temperature the oil in the engine becomes too thin effectively to prevent excess friction and the consequent wearing away of engine parts. Moreover, the molecules of the metals move farther apart when heated, and the subsequent expansion causes the moving parts of the engine to stick and cause increasing friction and loss of power. For these reasons, all aircraft engines must be equipped with an adequate cooling system. Aircraft engines may be cooled by either or both of two systems; they may be air-cooled or liquid-cooled.

The transfer of heat. Heat is a form of energy, and as such can be explained by laws of physics. Heat energy, and most other forms of energy, can be changed to mechanical energy (energy of motion). The greater the amount of heat energy changed to mechanical energy of the propeller, the more efficient the engine will be. The difficulty involved here is that only about 25 per cent of the heat does useful work, and the remaining unused 75 per cent must be removed to prevent overheating. There are three principal methods of transferring heat: (1) by *conduction,* (2) by *convection,* and (3) by *radiation.*

Heat is transferred by *conduction* by the motion of the molecules making up the substance. If one end of an iron rod is heated, the heat travels through the rod, and eventually the other end becomes heated. According to accepted scientific theory, the molecules closest to the heating element move much faster and strike harder than do those farther away. The faster-moving molecules set their neighbors in more rapid motion by collision, and in this manner all of the molecules in the rod are caused to move faster. The essential thing to remember about heat transfer by conduction is that the transfer is made by contact between molecules.

Laboratory Exercise 24. By means of paraffin or sealing wax attach ball bearings or marbles to an iron rod a foot or more in length, at intervals of three or four inches. Heat one end of the rod with a burner and note the results. (See Fig. 28 on page 75.)

The transfer of heat by *convection* is an entirely different process and is always associated with fluids (either liquids or gases). When a fluid is heated, it expands by increased molecular motion. Because of the fact that there are fewer molecules in a given volume after heating than before, the heated fluid becomes lighter (less dense) and is pushed upward by the cooler, denser fluid surrounding it. On the other hand, because of nature's constant effort to maintain equilibrium, cooler fluid flows in to take the place vacated by the rising warm fluid. The result is the same as in the air mass movements studied in the unit on meteorology.

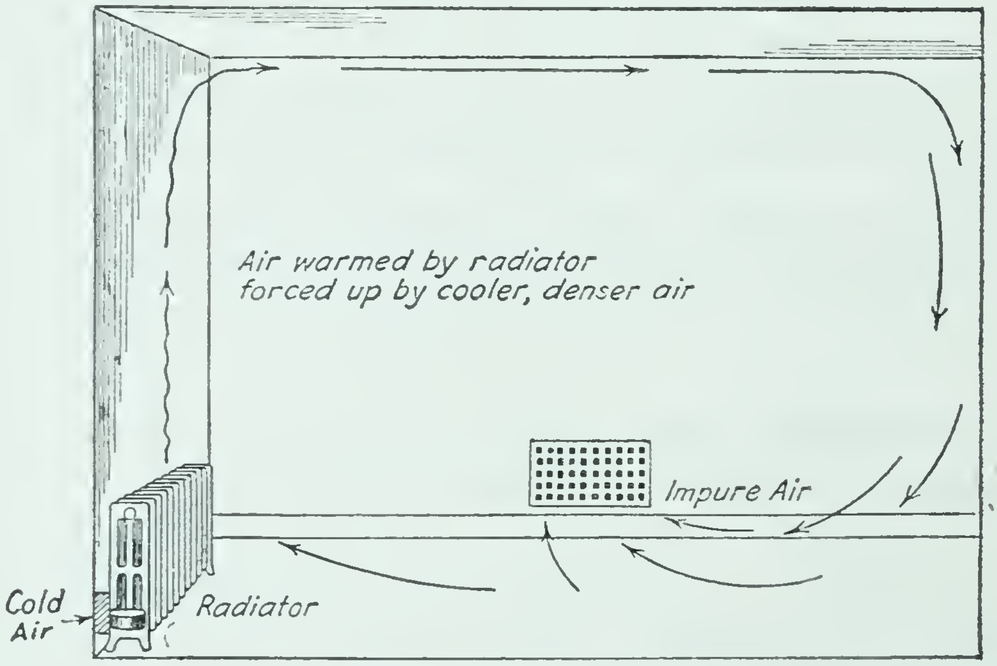


Fig. 158. Convection

Laboratory Exercise 25. Fill a battery jar with cold water. Equip a small flask with a two-hole rubber stopper in which are inserted two glass tubes as shown in the diagram. Fill the flask with hot water colored with ink or potassium permanganate, and set it in the battery jar. Explain the results.

The transfer of heat by *radiation* is different from either of the other two methods of heat transfer. The earth receives heat from the sun, which is about 93,000,000 miles away. This heat must pass through space in which there are no molecules and, consequently, no fluids. It is evident, then, that conduction and convection cannot be of any help in transferring heat from the sun to the earth. The energy from the sun travels to the earth as a form of radiant energy, moving with the speed of light. When this radiant energy strikes the atmosphere and other material substances of the earth, part of the energy is changed to heat by absorption. A red hot stove, steam radiator, or hot airplane engine gives off radiant energy in the same manner. The stove feels hot because the radiant energy it gives off is absorbed by the body and changed to heat. The rate of heat transfer by radiation is directly proportional to the surface area of the radiating body. In other words, the greater the surface area, the more rapid the heat transfer. This is one of the reasons for making steam radiators in the form of a series of pipes.

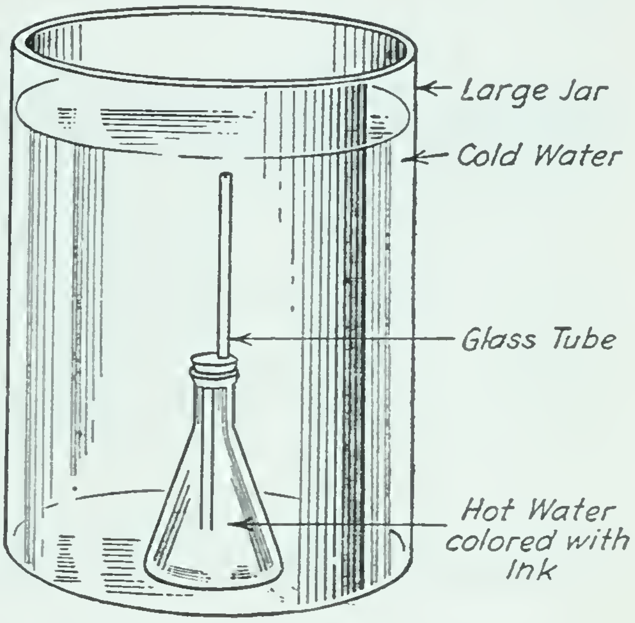


Fig. 159

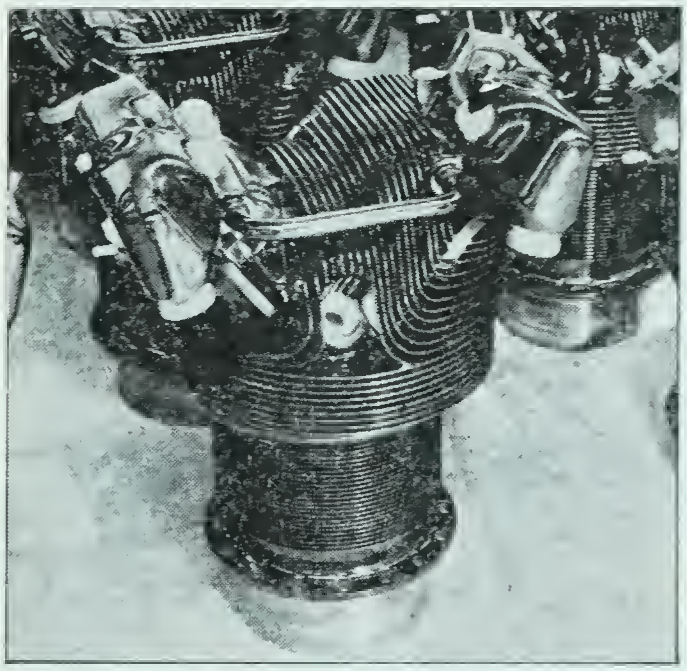


Fig. 160. Cooling fins of an air-cooled radial aircraft engine cylinder

Air-cooled engines. It has already been noted that radial, opposed, and some in-line and V-type aircraft engines are air-cooled. Air-cooled engines are cooled principally by *conduction;* the heat of the engine is conducted to the air by direct contact. In turn, the air is constantly renewed by the propeller blast, and the heat is thus carried away. Part of the heat, however, is removed by radiation and convection. Twenty per cent of the heat of combustion must be removed by these three methods, but before this can be accomplished, the heat must be transferred to the outside surfaces of the engine by conduction.

Since the rate of conduction depends on the area exposed to the circulation of the air, engineers have devised special "finned"

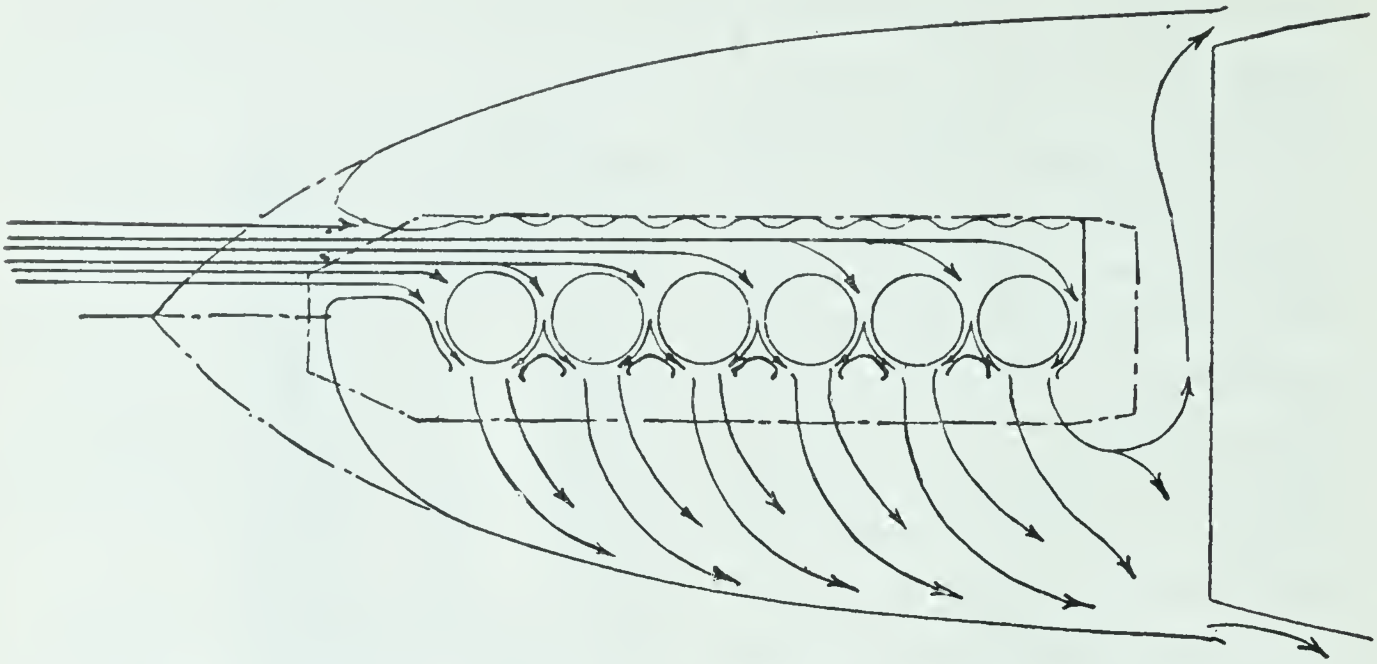
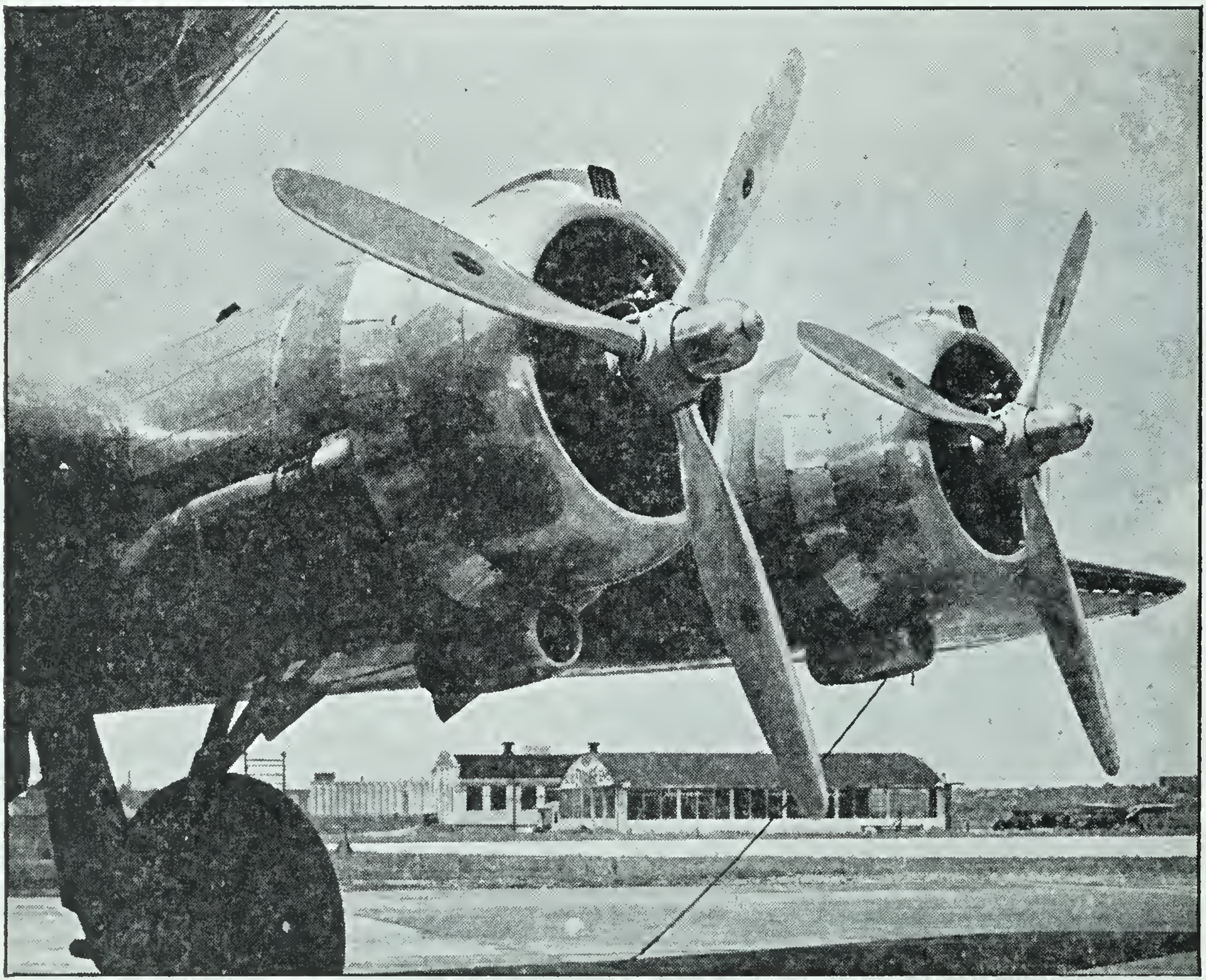


Fig. 161. Baffle arrangement in a typical in-line, six-cylinder, air-cooled engine



Courtesy Transcontinental and Western Air, Inc.

Fig. 162. Left engines of a T.W.A. Stratoliner showing cooling flaps ("turkey feathers") in open position

surfaces to increase the rate of cooling of the cylinders. These fins greatly increase the external surface area of the cylinders.

In "twin-row" radial engines or air-cooled V-type and in-line engines the rear cylinders do not ordinarily receive as much direct air circulation as do the front cylinders. To improve the air circulation about the rear cylinders, *baffles* are installed to deflect the air, much as the baffles in a car heater deflect the hot air as it passes from the heater.

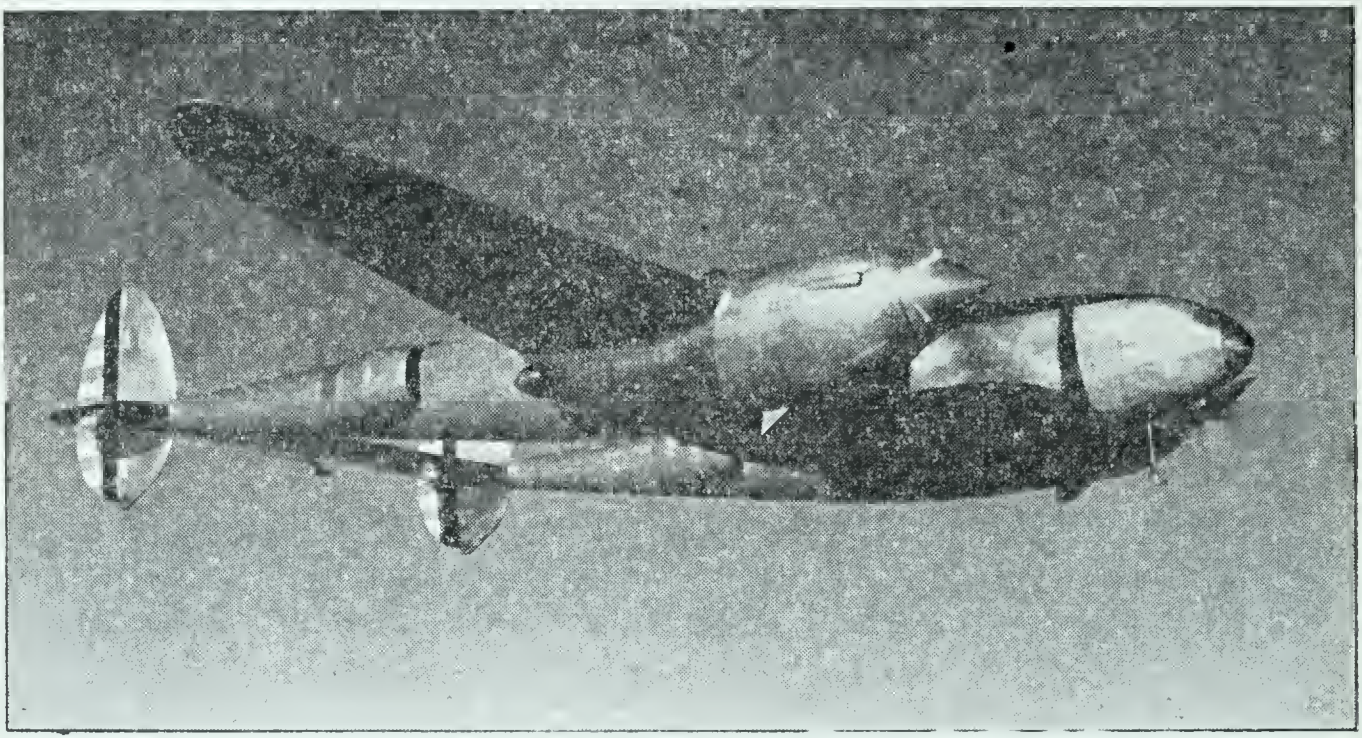
For many years air-cooled engines went unstreamlined because it was thought they would become too hot if enclosed. Engineers have since developed "cowling," which allows streamlining without excessive operating temperatures.

An air-cooled engine should be kept very clean, since a layer of grease and dirt insulates the engine against the cooling effect of the air flowing over it.

Liquid-cooling systems. Liquid-cooled engines include the in-line and V-type engines of large horsepower. It has been called to the reader's attention that the liquid-cooling system in aircraft engines is very similar in principle to the cooling system used in automobiles. One great difference between the two, however, is the kind of liquid used. Whereas automobile engines use water, most aircraft use a substance known as *ethylene glycol.* This substance is sold under the trade name of Prestone and is commonly used in automobiles as an anti-freeze. Prestone has several advantages over water as a cooling liquid in airplanes: it has a higher boiling point than water and will not boil away so easily; it expands less than water when heated; it acts as an anti-freeze in winter weather or for very high altitude flying; and it requires a smaller circulating system because less liquid is actually needed.

Liquid-cooled cylinders are surrounded by compartments called "jackets," and it is through these jackets that the cooling liquid is forced. A small centrifugal pump usually pumps the cooling liquid into the jackets, where the liquid absorbs the heat from the cylinders, expands, and passes through outlets at the top of the cylinders into an expansion tank. As the liquid becomes cooler, it becomes heavier and drops down into the radiator, where it circulates through a great number of small metal tubes. The radiator is exposed to the airstream, which passes around the tubes and conducts the heat away from the liquid. Radiators are usually below the engine or streamlined into the wings. The P-38 interceptor plane, however, has its radiators mounted in the double fuselage behind the engine. (See Fig. 163.) After the liquid is cooled in the radiator it is again pumped to the cylinder jackets and recirculated.

The air passages in the radiator should be cleaned regularly to avoid the accumulation of dirt and insects. Clogging will cause poor circulation of air in the radiator and consequent overheating of the engine.



Courtesy Lockheed Aircraft Corporation

Fig. 163. A P-38 Interceptor. The Prestone engine-coolant radiators are behind the wings on the double booms. The opening just beneath the wing is the air intake for the supercharger, and the air scoops under the propeller spinners are for the oil radiators.

Liquid-cooling vs. air-cooling. The following summary will show the advantages of each type of cooling system.

Air-cooled engines are, in general:

1. Shorter and take up less space in the length of the ship.
2. Seldom troubled by cooling failures.
3. Lighter in proportion to horsepower. (They carry neither "jackets," radiator, liquid, nor plumbing.)
4. More accessible to repair.
5. Less vulnerable to gun fire.

Liquid-cooled engines, in general:

1. Allow better streamlining and increased speed.
2. Provide greater visibility for the pilot.
3. Have better temperature controls.
4. Permit a more rapid analysis of the temperature of the engine.

Exercise 26. Prolonged running on the ground is likely to cause serious overheating of an airplane engine. How do you account for this? What are the dangers of overheating?

Problem 6. Why is oil important in modern airplane engines?

The necessity for lubrication. The efficiency of the airplane engine is only about 25 per cent. This means that of the entire heat energy formed by combustion in the cylinders, only one fourth may be used by the propeller in supporting and moving the plane. Approximately 5 per cent of the heat energy is lost in overcoming friction in the engine, and, if it were not for the presence of oil, the loss would be much greater. The lubricating oil in an airplane engine also serves in two other important capacities. It conducts heat away from the heavily worked bearings and seals the pistons against loss of power.

Friction is defined as the resistance to the sliding of one surface upon another. A perfectly smooth surface is an impossibility; surfaces that appear smooth to the naked eye are very irregular when viewed under a microscope. These surface irregularities are responsible for friction. When the hands are rubbed together rapidly, they become warm because of friction; all sliding surfaces are warmed the same way. The amount of heat produced by sliding surfaces is increased by increasing the relative speed of the surfaces, and by increasing the force holding

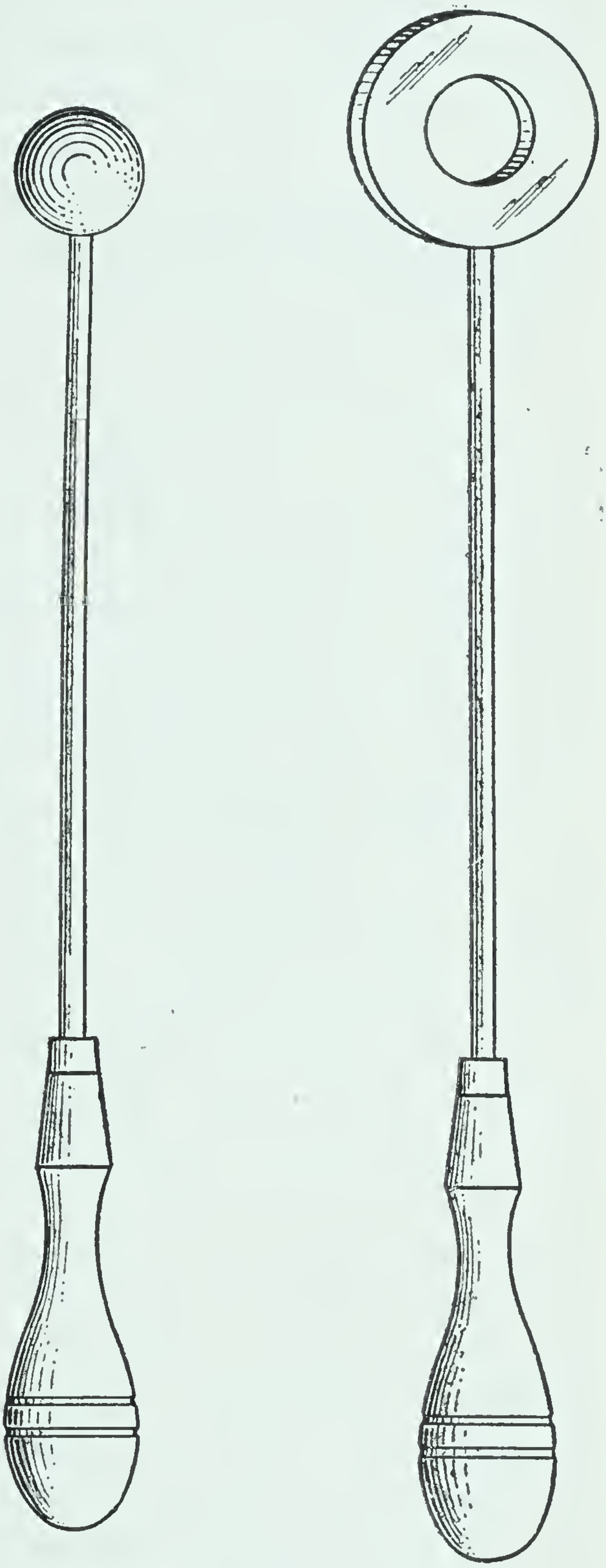


Fig. 164

them together. Meteors that streak into our atmosphere burn at extremely high temperatures because of the friction between meteors and air. Primitive man produced fire by rubbing two pieces of wood together; brakes on an automobile become warm with continued use. Friction exists between two solids, between a solid and a liquid, between a solid and a gas, in liquids, and in gases. In all cases heat is developed, but the heat developed between the molecules of a liquid is less than that between the molecules of a solid and the molecules of a liquid.

If the moving parts of an engine are not lubricated, friction results in a great increase in temperature and in expansion of the parts. Different metals expand at different rates, and as a result some parts fit closer; this produces an increase in pressure between the two surfaces. An increase in pressure causes increased friction, loss in power, and the wearing away of the engine parts. If the expansion of a piston becomes too great, the piston will fit so tightly in the cylinder that it will "seize" and stop the engine; this is termed "freezing" of the engine and is disastrous in aircraft.

Laboratory Exercise 27. Using the apparatus shown in Figure 164, push the ball through the ring. Heat the ball over a Bunsen flame for a few minutes, and try again to push it through the ring. Explain what happens. Now heat the ring, and try again to pass the ball through the ring. What conclusions may be drawn?

In an airplane engine bearings are located at points where one part turns within another. Examples of these are the connections between connecting rod and crankshaft, and between connecting rod and piston pin. These bearings are subjected to great pressures, and it is essential that excess friction be prevented. In order to prevent friction, a film of lubricating oil is maintained between the rubbing surfaces. This oil has two properties that make it very valuable as a lubricant. The first is *adhesion,* or the tendency of the oil molecules to cling to the metal parts of the bearings. The second is *cohesion,* or the tendency of the oil molecules to cling to each other. The oil film inserted between the metal parts is thick enough to provide a layer of oil molecules on each surface and several layers in between.

As shown in Figure 165, the friction between the oil layers *A* and *B* and the adjacent metal parts is greater than the friction between layers *A* and *B* and the oil layers between them. As a result the outermost layers of oil remain stationary, and all friction is reduced to that between the inner layers of oil. To illustrate this effect, if a deck of cards is held between the palms of the hands and an effort is made to slide one hand past the other, the hands will not slip on the cards. Instead, the innermost card layers will slide past each other because the friction between two cards is less than the friction between a card and the palm of the hand. The oil molecules slide past each other very easily, producing less heat. Furthermore, since the metal parts do not rub together, excessive wear on the bearings is prevented.

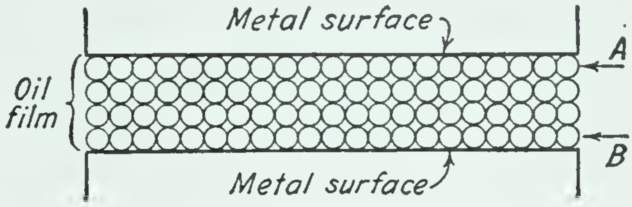


Fig. 165. Oil-film lubrication

Aircraft oils. Because bearings are subjected to high pressures, it is necessary that a lubricating oil possess certain qualities. It must have enough body so that it will not be squeezed out from between the bearings when pressure is applied. On the other hand, it must not be so heavy that it cannot be forced between the moving parts by the oil pump. The body or fluid friction of an oil is called *viscosity* and is measured by the rate of flow at a given temperature. An oil that is thick and flows slowly is said to be more *viscous* than a thin, easy-flowing oil. As an illustration, molasses flows more slowly and is, therefore, more viscous than water. Moreover, the colder the molasses becomes, the more viscous it becomes, and the more slowly it will flow. The same thing is true of lubricating oil; the colder it becomes, the more viscous it becomes. On the other hand, the warmer the oil, the thinner and less viscous it becomes. These changes in viscosity due to changes in temperature must be considered in choosing oil for airplane engines. Planes that fly at high altitudes or in severe cold weather must not use too heavy an oil, for it will not circulate freely and, therefore, will not lubricate the engine properly. Similarly, planes that fly in tropical regions must not use too light an oil. If the oil is too light, the interposing oil layers will be squeezed out from between the bearings. The airplane-engine manufacturer includes with each engine information concerning the kind and grade of oil to be used in that particular engine. These specifications of the manufacturer should be followed closely.

Laboratory Exercise 28. Fill two $\frac{3}{4}'' \times 8''$ test tubes with oil, one with kerosene or distillate, and the other with engine oil. Stopper the two test tubes with rubber stoppers so as to leave a small air space between stopper and oil. Now invert the test tubes simultaneously. Explain the action of the air bubbles.

Quantity of oil and oil consumption. The oil supply carried in flight is also a very important factor. The Civil Aeronautics Board requires that a plane carry at least one gallon of oil for every twenty gallons of gasoline, and never less than one gallon for each seventy-five horsepower on the smaller engines. Planes that have two or four engines are usually required to have a separate oil supply for each engine. In the event that the oil supply system of one engine should fail, there would be no interference with the operation of the other engines. The oil tank should be 10 per cent oversize to allow for expansion of the oil when it becomes heated.

There are three ways in which oil can be consumed in an engine: (1) burned in the combustion chamber, (2) lost as oil mist or vapor from the engine "breather" (the breather is an opening that allows air to pass in and out of the engine crankcase with change of pressure), and (3) leakage through the bearings at the ends of the crankshaft and other shafts that protrude from the engine. Engine speed probably is the most important factor affecting oil consumption. Since the oil pressure pump is geared to the engine, the oil pressure increases with engine speed until maximum pressure is reached, beyond which a pressure relief valve maintains constant pressure. Usually maximum pressure is reached at low speed, so that the effect of speed upon oil pressure between the pump and main bearings is negligible. However, centrifugal force exerted on the oil in the drilled passages in the crankshaft increases the oil pressure very appreciably at the connecting rod bearings and, therefore, increases the rate of oil flow through these bearings. An increase in engine speed results in a higher oil temperature, which reduces the viscosity, thus enabling more oil to flow through the bearings. When more oil flows, more oil is sprayed on the cylinder walls. At high speeds the piston rings (to be discussed later) do not follow the cylinder wall as closely as at low speed, but tend to act something like a surf board, riding over the oil film. Under this condition more oil is passed to the combustion chamber and burned instead of being scraped back to the crankcase.

High engine temperature and low oil viscosity tend to increase the losses from the shaft ends and "breather" pipe. These losses also are increased by more *blow-by,* or gas flow past the piston rings into the crankcase. The gas increases the vapor pressure in the crankcase, which forces more oil and oil vapor or mist out of the crankcase through the "breather."

Oil consumption is also increased by the wearing away of the bearings. This provides larger areas through which oil can flow for a given oil pressure and, consequently, causes more oil losses by leakage and more oil to be sprayed on the cylinder walls.

Piston rings serve three functions: (1) they seal the piston in the cylinder so that no power will be lost by escaping gases; (2) they return excess oil to the crankcase; and (3) they conduct heat from the piston head to the cylinder walls. Figure 166 shows a typical aviation piston and ring assembly. The rings are elastic and spring out to make contact with the cylinder walls, thus forming a gas seal when properly lubricated. Piston rings are split so that they may be sprung into place in the grooves in the piston, and also to insure that they will have sufficient elasticity to take the form of the cylinder at the different points in their travel.

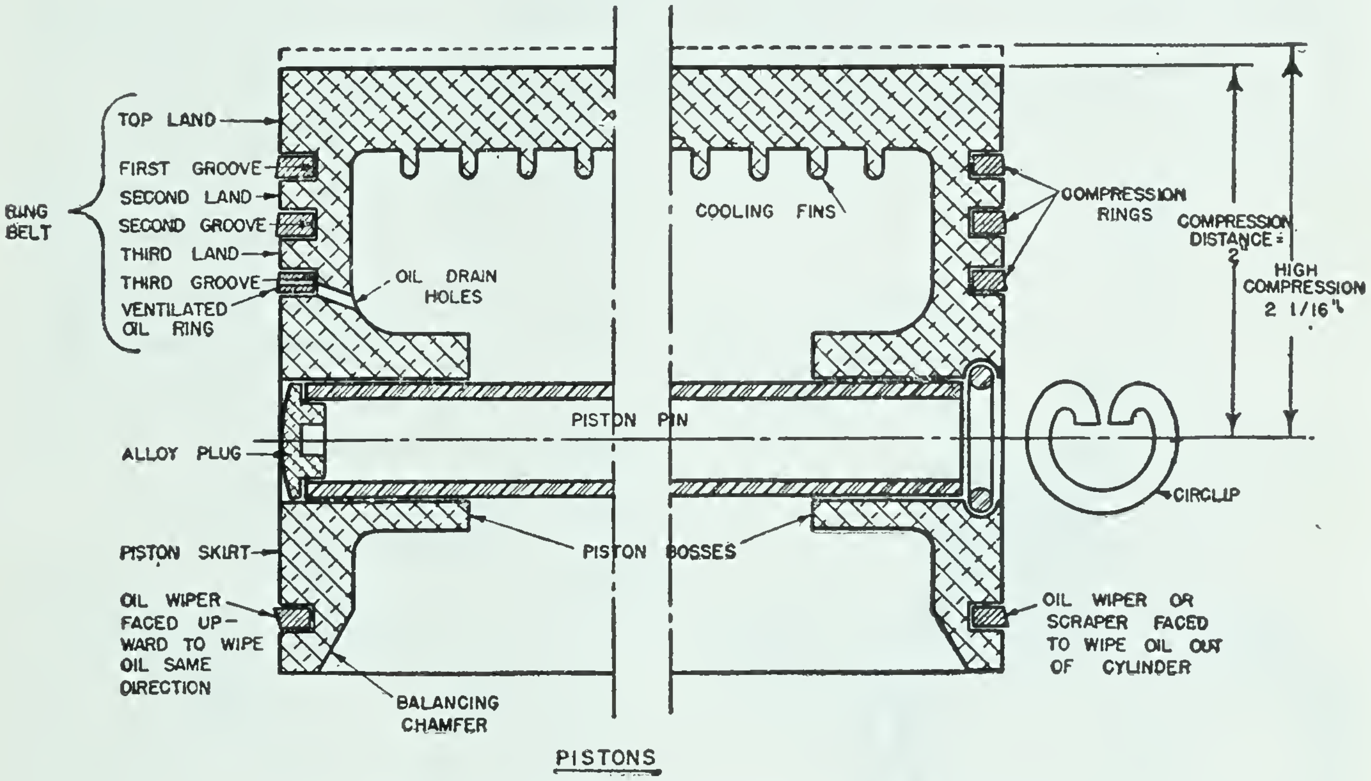


Fig. 166. Aviation-piston and piston-ring assembly

Oil temperature control. An airplane engine is called upon to perform under a full range of temperature, moisture, altitude, speed, and acceleration. An airplane may operate under all of these conditions in a very short period of time. For proper lubrication it is important that the oil not become too viscous or too thin; this requires that the cooling of the oil be controlled. The oil cooler is merely a temperature regulator, which maintains the oil temperature between prescribed high and low temperatures.

During winter operation of engines at low temperatures, the engine oil should be drained immediately after the completion of a flight to prevent its congealing in the engine. The oil should be warmed and returned to the oil tank just before the next flight is begun. It is also advantageous in very cold weather to put hot fluid in the cooling system of liquid-cooled engines in order that the oil on the cylinder walls and in bearings may be warmed.

Oil distribution systems. In airplanes nearly all bearings and sliding surfaces are lubricated by a pressure system. The advantages of the pressure system are: (1) positive introduction of oil to the bearings, (2) cooling effect of the large quantities of oil that can be circulated through the bearings, and (3) satisfactory lubrication in various engine positions. Pressure lubrication systems are of two types (a) wet sump, and (b) dry sump.

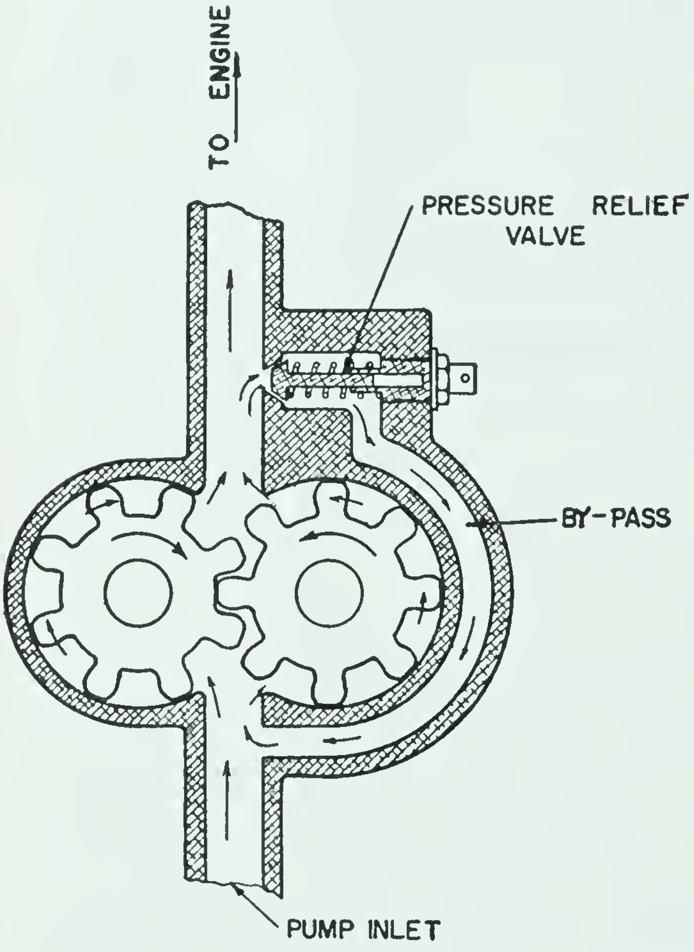


Fig. 167. Gear-type oil pump

The *wet sump* system consists of a sump (an oil reservoir located in the crankcase) in which the oil supply is contained. The level of the oil is indicated by a vertical rod attached to a suitable float. The bottom of the sump is equipped with a screen strainer that removes undesirable particles from the oil. The rotation of a gear pump, driven by the engine, causes oil to pass between the gears and the pump body as illustrated in the accompanying diagram (Fig. 167). Increase in speed of the pump because of increased engine speed, and changes in viscosity of the oil are compensated for by the tension on the relief valve springs in the pump. The pump is designed to create a greater pressure than probably ever will be required in order to compensate for wear of the bearings surfaces or thinning of the oil. The parts oiled by pressure throw a spray into the cylinder and piston assemblies. This is called *splash* lubrication. After lubricating the various units on which it splashes, the oil drains back into the sump, and the cycle is repeated.

The main disadvantages of the wet-sump system are:

1. The oil supply is limited to the sump capacity.

2. Oil temperatures are likely to be high on large engines because the oil is subjected to the operating temperatures of the engine almost continuously.

3. Provisions for cooling of the oil are difficult to arrange.

4. The system is not readily adaptable to inverted flight, since the entire supply will flood the engine.

The main advantages of the wet-sump system are:

1. It may be utilized in the lowest power range where the volume of heat generated is not so great and inverted flying is not a common practice.

2. A simpler engine design is made possible, since fewer moving parts are needed.

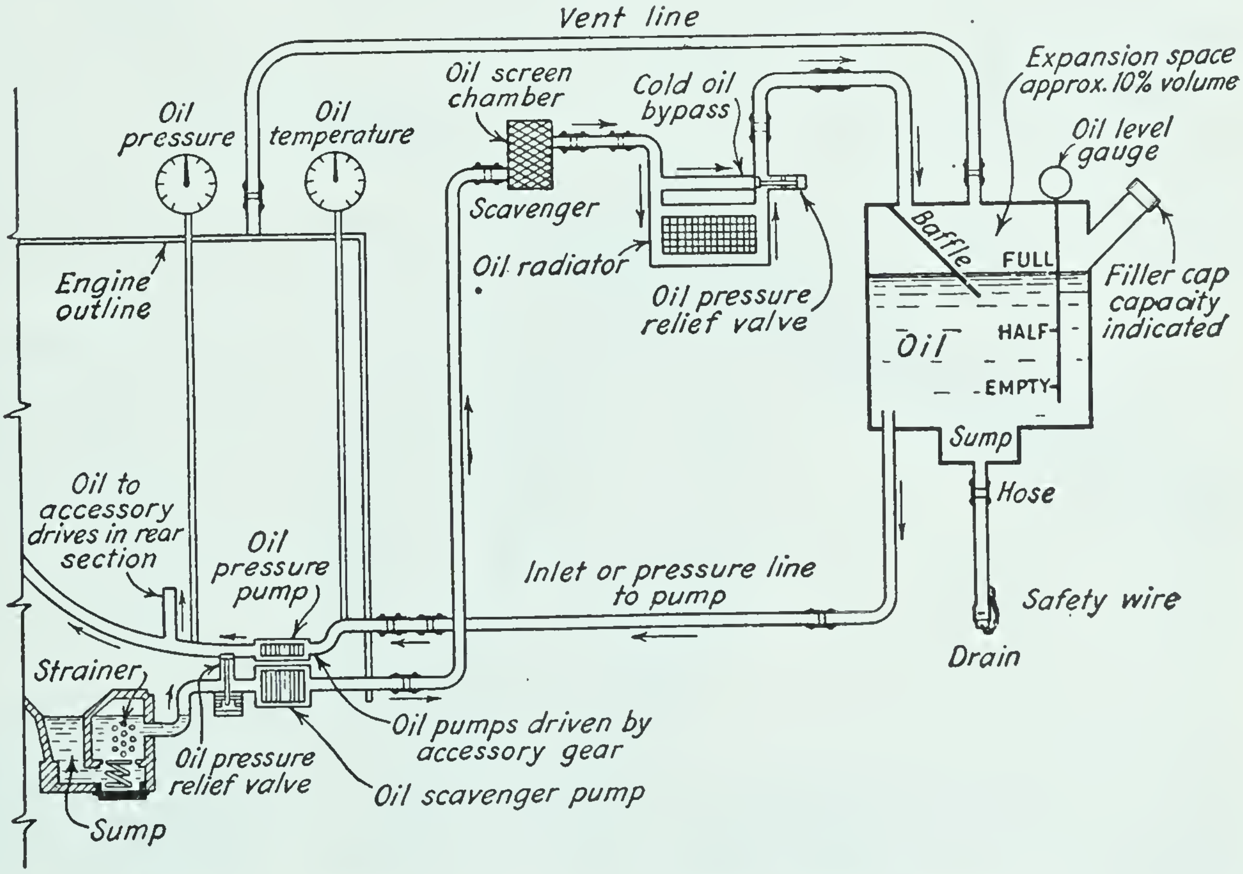

Vent line
Oil pressure
Oil temperature
Oil screen chamber
Cold oil bypass
Expansion space approx. 10% volume
Oil level gauge
Scavenger
Baffle
FULL
Engine outline
Oil radiator
Oil pressure relief valve
Filler cap capacity indicated
Oil
HALF
EMPTY
Sump
Hose
Oil to accessory drives in rear section
Oil pressure pump
Inlet or pressure line to pump
Safety wire
Drain
Strainer
Oil pressure relief valve
Oil pumps driven by accessory gear
Oil scavenger pump
Sump

Fig. 168. Schematic layout of dry-sump lubrication system

The *dry-sump* oiling system is used the more widely at present, especially on larger aircraft. The main oil supply is carried in an external tank located relative to the engine in such a manner that excessive head pressures do not develop, thereby avoiding flooding of the engine while in storage. The capacity of the tank, exclusive of the expansion space, varies with the requirements of the engine, fuel capacity, etc. The preceding diagram shows a typical arrangement of the various external parts of the dry sump system. The oil radiator is constructed similarly to the liquid-cooling system radiator.

The dry-sump system does not have the disadvantages common to the wet-sump system.

The lubricating system should receive careful and regular attention. When the engine is overhauled, the oil tank should be thoroughly cleaned, since foreign material might flake while the tank is empty and pass into the oiling system when the engine is returned to operation. Oil that has been used too long loses much of its lubricating value and should be replaced at regular intervals. The life of the engine oil varies between 15 and 100 hours of running time. The pilot and mechanic should remember that the "highest-priced oil is cheaper than machinery."

Exercise 29. Prepare a comprehensive report on oil refining.

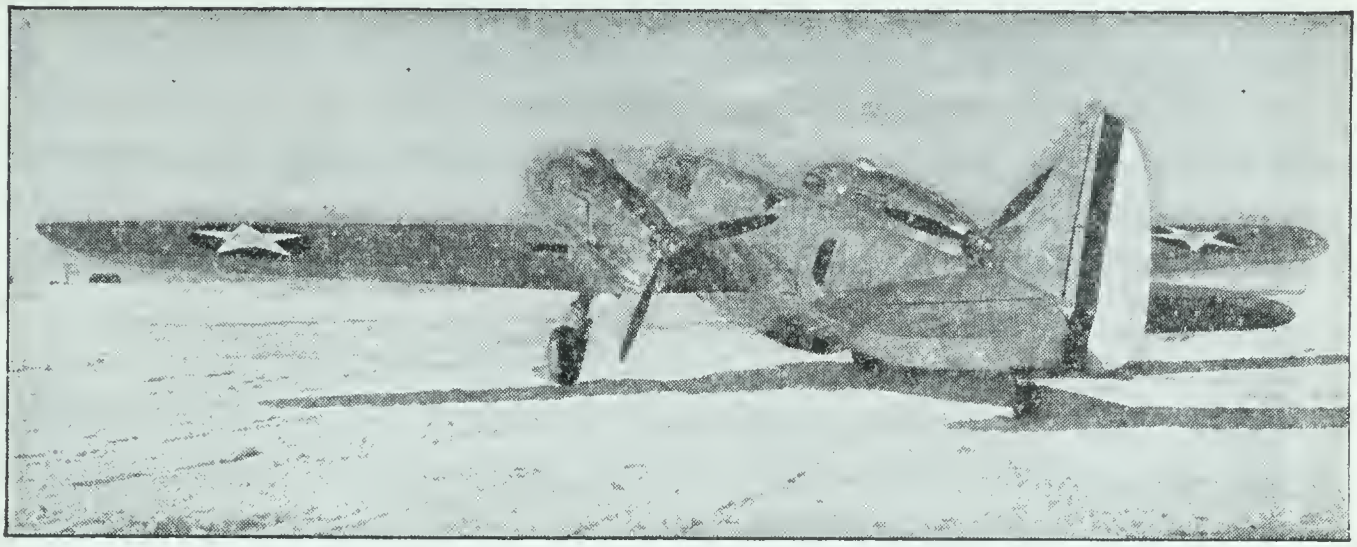
Exercise 30. Summarize the probable effects of improper or insufficient lubrication of an airplane engine.

Exercise 31. Why is it necessary to use a heavier viscosity of oil in an aircraft engine than in an automobile engine?

Problem 7. What improvements have been made in propellers since the days of the Wright brothers?

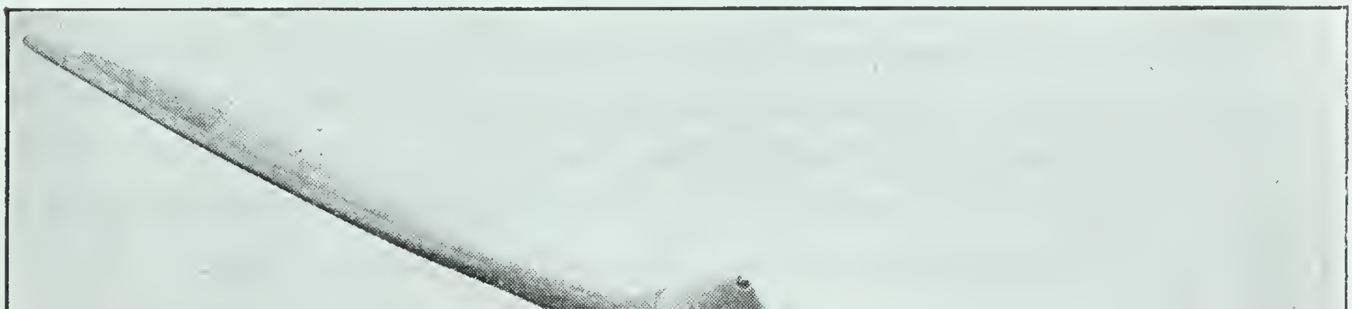
Without the propeller, the airplane engine is useless, and for this reason the propeller is considered a vital part of the power plant. Propellers may be classified according to their position with respect to the wing: (1) the *tractor* type, which is mounted in front of the wing and "pulls" the plane through the air; and (2) the *pusher* type, which is mounted behind the wing and "pushes" the plane through the air. Both types are in use, but the majority of planes use the tractor type. Propellers may also be classified according to (1) the material from which they are made, (2) the number of blades, and (3) the manner in which the "pitch" or angle of the blades may be arranged.

Materials used in propellers. Early propellers were made of wood for want of a better material, and many light airplanes still make use of wooden propellers. The most popular wood for their manufacture is birch, although oak, walnut, mahogany, and other woods are sometimes used. The common procedure used in making



Courtesy Bell Aircraft Corporation

Fig. 169. A pusher-type plane



Courtesy Pan American Airways

Fig. 170. A wooden propeller. Note the layers of wood making up the propeller, and the metal sheathing of leading edges and tips. The large opening in the nose of the plane is the air inlet to the air-cooled cylinders.

such a propeller is to glue a number of boards (three fourths to one inch thick) together and then place them under pressure at 100° F. until the glue thoroughly dries. The temperature of the glue when applied and the temperature at which it dries must be controlled to prevent distortion of the wood. The propeller is then shaped roughly and allowed to stand for about ten days to allow all stresses and strains in the wood to adjust themselves. Next the propeller is shaped to very nearly its finished dimensions and again allowed to stand. Finally the blade is hand-scraped to exact shape and thoroughly tested for balance, pitch, hub dimensions, etc. It is very important that a propeller be perfectly balanced, both statically and dynamically. If one blade is slightly heavier than the other, it will cause considerable vibration and damage. The leading edges of wooden propellers are usually sheathed with a metal strip to protect them from splintering under the impact of hail, rain, sand, pebbles, shrubs, weeds, and other materials with which they may come in contact.

The main reasons for the use of this type propeller on light aircraft are low cost, ease of fabrication for any desired ship-and-engine combination, and light weight. On the other hand, certain troubles are encountered, *e.g.,* warping of the blades, abrasion and loosening of the leading edge sheathing, and breakage of blades due to "nosing over" of the airplane.

Metal propellers, because of their durability and freedom from warping and splintering, are used very extensively. Propellers of this type may be forged in one piece or forged in separate pieces. If the pitch of the propeller is to be adjustable, the blades are molded separately and attached usually to a steel hub. Metal propeller blades are usually made of an aluminum alloy, duralumin, or some other similar alloy that has the qualities of both lightness and strength. Some satisfactory steel blades with hollow sections for light weight have been made.

Another material used in propellers is bakelite, which is used in combination with wood in the manufacture of propellers known as the Schwarz type.

Number of blades. Propellers may have two, three, or four blades, depending upon the use for which they are intended. The two-bladed propeller is easiest to build and balance and is more efficient at high speeds than either of the other types. For these reasons it is very desirable. On the other hand, three- and four-blade types are sometimes necessary to absorb the full power of large engines, since a two-blade propeller would require too great a pitch or diameter. One of the reasons for the greater efficiency of the two-blade propeller over the three- or four-blade is that the two-blade type acts in less disturbed and therefore denser air. In other words, the two-blade propeller cuts through the same section of air fewer times for a given r.p.m. than does a three- or four-blade propeller.

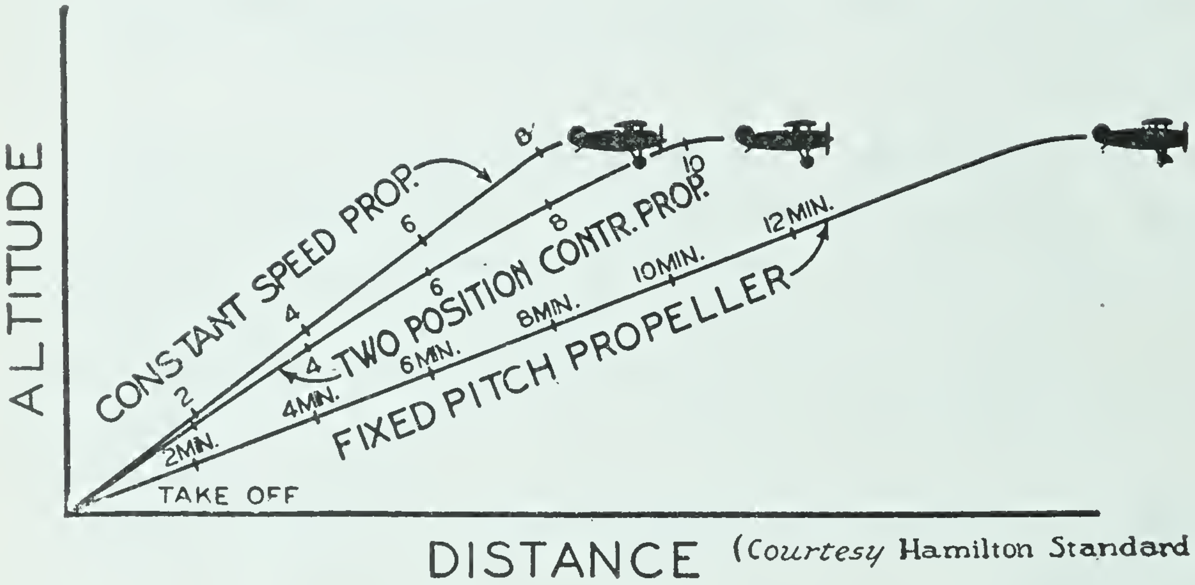
Two generalizations may be made about properly designed propellers. These are: (1) the higher the speed the lower the efficiency, and (2) the larger the diameter the greater the efficiency. The efficiency of a propeller is the ratio of the power exerted by the rotating blades to the power expended by the engine in turning the blades. This efficiency in airplanes varies between 50 and perhaps 90 per cent. This means that between 10 and 50 per cent of the engine power is lost by the propeller. Propellers are usually considered, however, to have an efficiency of 75 per cent.

Pitch and blade angle. The geometrical pitch of a propeller is the distance a propeller moves forward in one complete revolution if there is no slip. Effective pitch is the actual distance a propeller moves forward in one complete revolution. In other words, effective pitch is geometrical pitch minus slip. Pitch may be varied by changing the blade angle. Propellers may also be classified as: (1) *fixed pitch* (wood), (2) *adjustable pitch* (wood or metal), (3) *controllable pitch* (metal), (4) *constant speed* (metal), and (5) *feathering and constant speed* (metal).

Fixed-pitch propellers get their name from the fact that the angle of the blades cannot be changed once the propeller is made. This is a great disadvantage when flying in the stratosphere, for the pitch must be greater there than at sea level in order to avoid loss of power. Fixed-pitch wooden propellers of the earliest type were made in one piece, but modern ones of either wood or metal have the blades made separately and then mounted solidly in a steel hub.

Adjustable-pitch propellers have a provision for the adjustment of the angle of the blades. This adjustment must be made when the ship is on the ground and the propeller not in motion. The important advantages of this type of propeller are that the blade angle may be varied to compensate for various altitudes of operation, and damaged blades may be replaced more economically. It is well to keep in mind that in flight the pitch of an adjustable propeller is *fixed.*

The action of a fixed-pitch type propeller may be compared to racing automobiles having but one forward speed. These automobiles are geared so highly that they have trouble getting in motion at low speeds and are generally set in motion by pushing. The development of larger and heavier aircraft has resulted in a heavier loading of the wings. This in turn has necessitated the "low gear" or low-pitch setting of the propeller in order to increase engine speed, power output, and propeller efficiency. In this manner the effective thrust to permit take-offs in a limited space is increased. Since "necessity is the mother of invention," a *controllable-pitch* propeller has been designed with two pitch settings that can be changed by the pilot while in flight. This is comparable to a two-speed transmission on an automobile, one gear ratio to get it in motion and the other to be used at higher speeds in order to obtain better all-around efficiency.

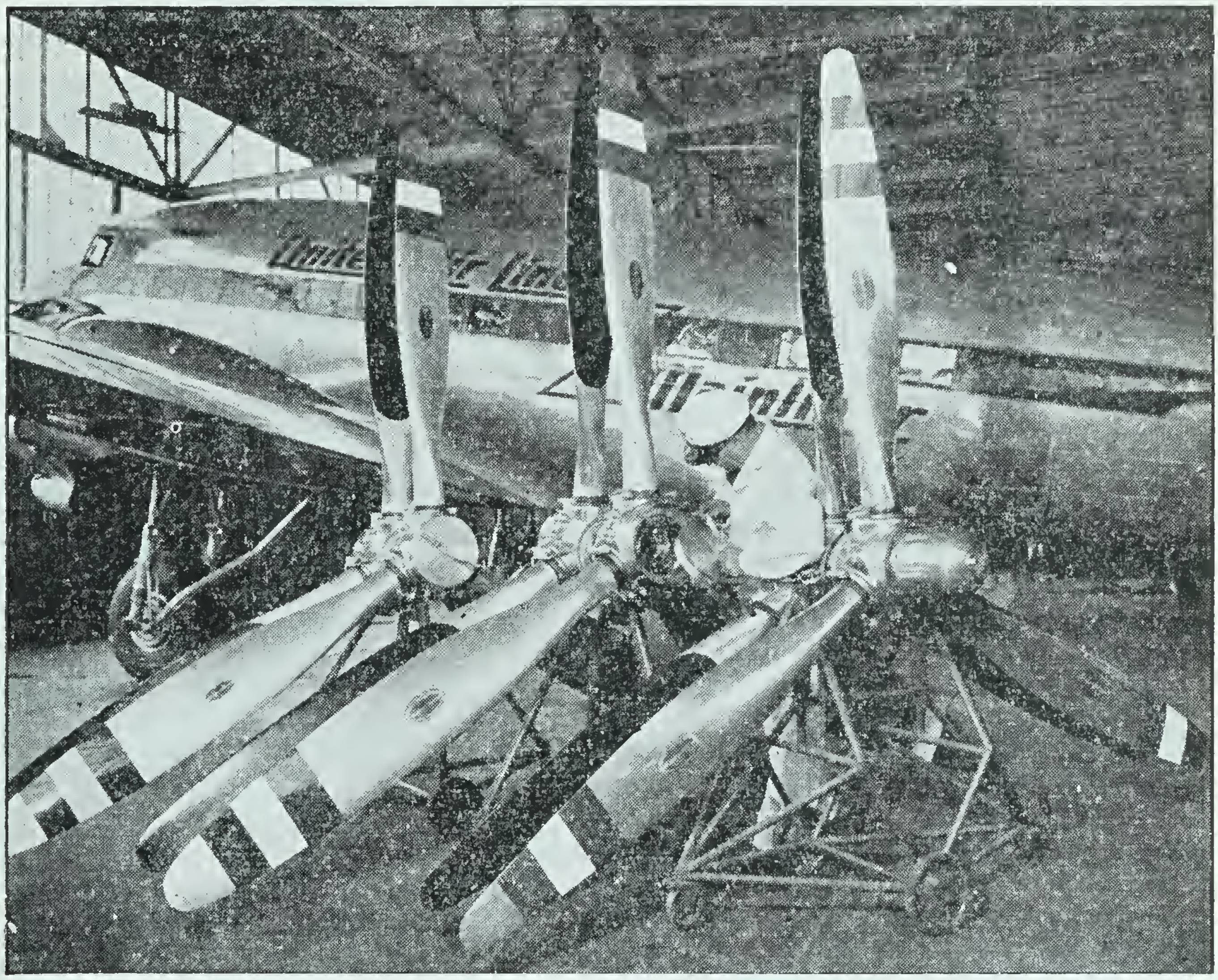


(*Courtesy* Hamilton Standard Propellers)

Fig. 171. Comparative airplane performance between constant-speed, two-position-controllable, and fixed-pitch propellers

With the arrival of multi-engine aircraft, the *constant-speed* propeller has been developed to relieve the pilot of the duties of keeping the engines "synchronized," or turning at the same speed. The constant-speed propeller is one whose pitch is automatically adjusted and controlled in flight by a governor. This automatic control of the pitch results in a constant engine speed and, once the engines are synchronized, the pilot need no longer concern himself with their control as to synchronization. The governor may be controlled by the pilot so that he may obtain any desired engine-operating speed without destroying the synchronization. When the engines are not synchronized, the noise and vibration are very disagreeable to those riding in the airplane.

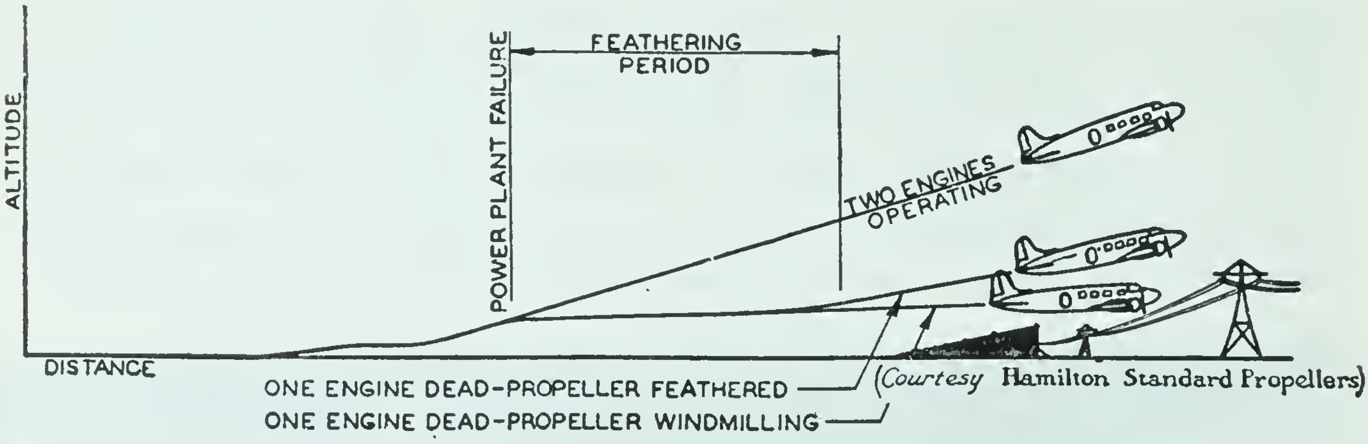
If an airplane engine breaks a connecting rod or a valve stem or an oil line, etc., it is necessary to stop the engine immediately to prevent its ultimate destruction. Turning off the ignition to that engine causes it to cease firing, but because of the "windmilling" of the propeller due to forward speed of the airplane, the engine continues to rotate. This windmilling of the propeller also constitutes an added drag, which must be overcome by the other engine (or engines) and, in some cases, sets up such severe vibrations that the engine is torn out of the airplane. To prevent this windmilling, there has been developed a *feathering* propeller in which the blades may be turned parallel to the line of flight, thus stopping the engine and reducing the drag. The entire feathering operation is accomplished in an average time of only nine seconds and is brought about either electrically or by means of hydraulic oil pressure supplied by a special pump.



Courtesy United Air Lines

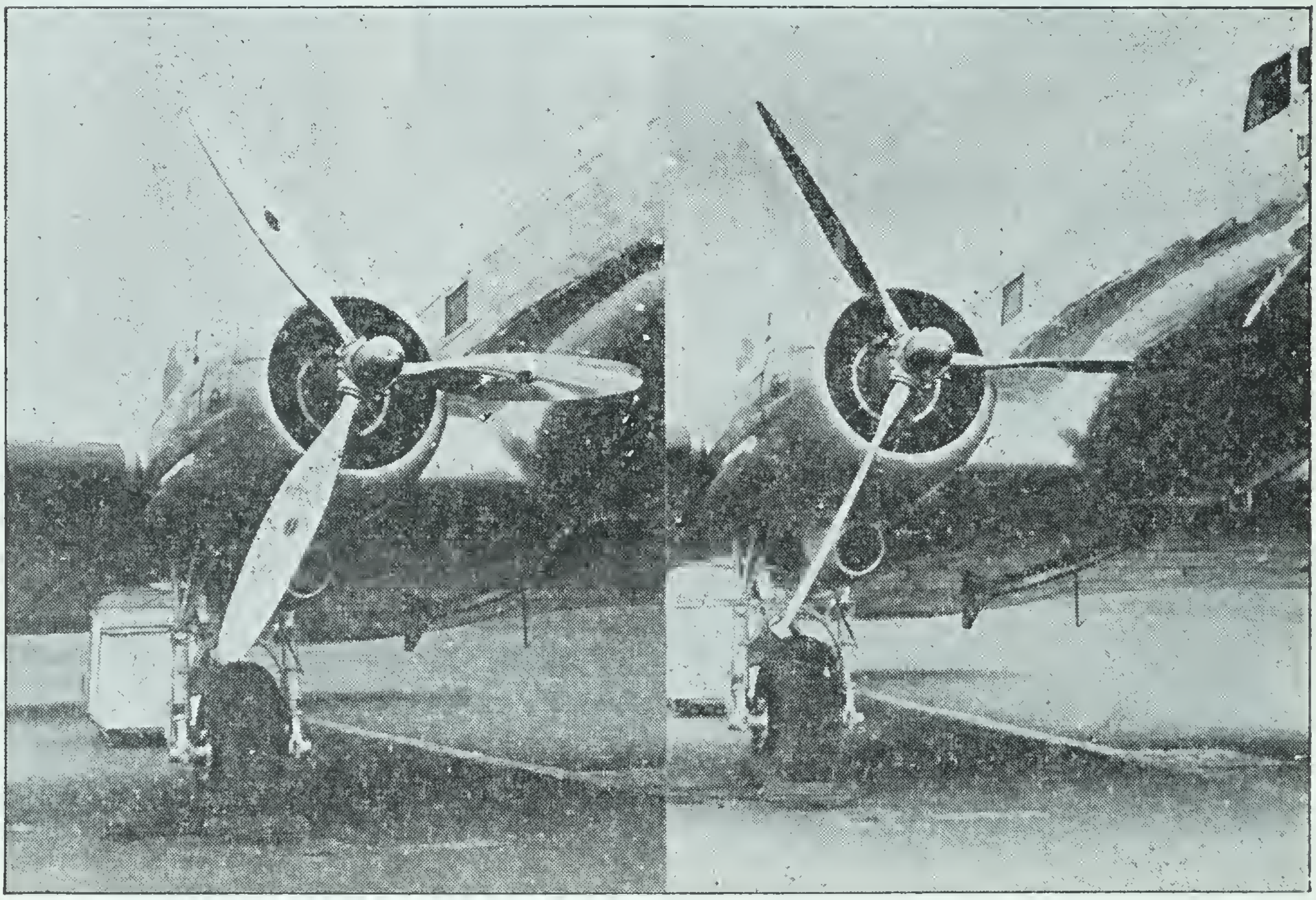
Fig. 172. Constant-speed propellers. Note the gears that control the pitch of the propellers.

Most of the fixed- and adjustable-pitch propellers used on light and medium-powered aircraft are equipped with two blades. On the



(*Courtesy* Hamilton Standard Propellers)

Fig. 173. One advantage of feathering propellers. The lower plane is headed for a crash.

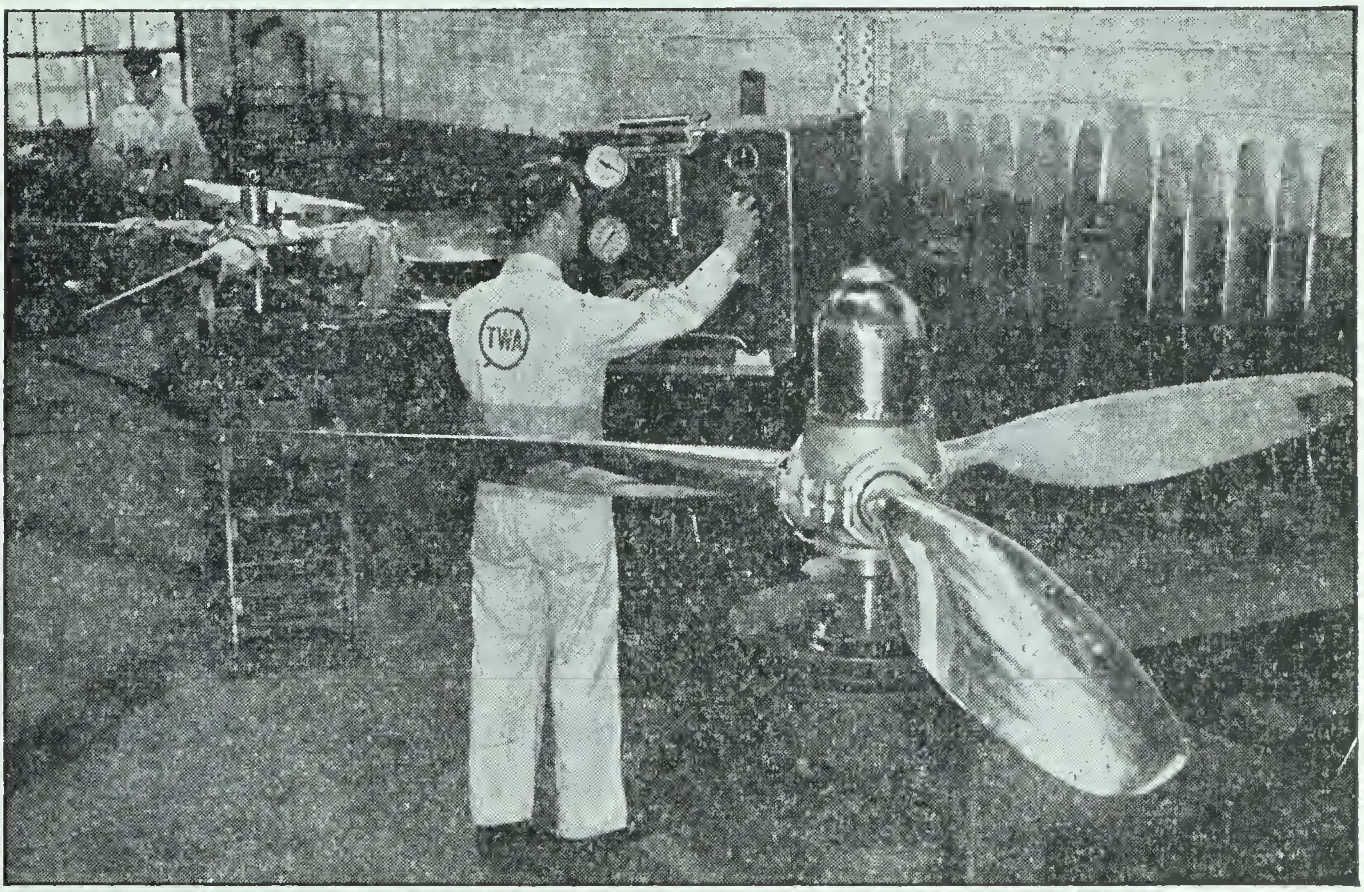


Courtesy Hamilton Standard Propellers

Fig. 174. A propeller in unfeathered and full-feathered positions

other hand, most of the controllable- and automatic-pitch propellers used on modern high-powered engines are of the three-blade type in order to furnish a means of absorbing adequately the power output of the engine. Greater increases in power output will require four- and possibly six-blade propellers. The number of blades that may be used is governed more or less by the speed of the airplane. In other words, the airplane should be fast enough so that the blades will be working in relatively undisturbed air.

Care of propellers. The balance of propellers is thoroughly checked at each overhaul. Any "pits" in the propeller blades (metal) caused by the impact of hail or some other material are removed. This is accomplished in the case of minor nicks by using a fine stone, but care must be taken that too much metal is not removed since the propeller would become unbalanced. If it is necessary to remove enough metal to upset the balance, the balance is restored by the addition of weight in the form of solder or some other material. A propeller with a hole in it should never be repaired; it should be replaced. Propellers that are badly bent or cracked should be returned for repairs to the factory, where proper equipment is available.



Courtesy Transcontinental and Western Air, Inc.

Fig. 175. An inspector checks a propeller to see that it has perfect balance

Since the propeller is an air foil that moves at an extremely great speed, it is essential that it be smooth in order to reduce air resistance. For this reason propellers are burnished glass-smooth at each overhaul.

Exercise 32. Prepare a report on aluminum alloys used in airplane construction.

Exercise 33. Prepare a report on the manufacture of metal propellers.

Problem 8. How can the pilot check on the condition of his engine?

The modern airplane engine is complex as well as powerful. All of the previously studied parts must function smoothly under widely varying conditions. In order that the pilot may know the general condition of his engine, it is necessary that he have certain engine instruments to help him detect trouble and avoid accidents. The most important of the engine instruments are: (1) the *tachometer,* which indicates the speed (r.p.m.) of the engine; (2) the *oil-pressure gauge,* which measures the pressure at which the oil is forced through the engine bearings; (3) the *oil thermometer,* which measures the general operating temperature of radial engines, or the *liquid thermometer,* which measures the temperature of liquid-cooled engines; (4) the *manifold-pressure gauge,* sometimes called the *supercharger gauge,* which measures the gas pressure in the intake manifold; and (5) *cylinder-head temperature gauge* (used in highly supercharged engines).

The tachometer. It is essential that the pilot know how fast his engine is running. The *tachometer* has a function similar to that of the automobile speedometer except that it indicates the number of engine revolutions per minute instead of miles per hour. If, in normal flight, the airplane engine should slow up because some part of the engine is not functioning correctly, the tachometer informs the pilot of approaching trouble.

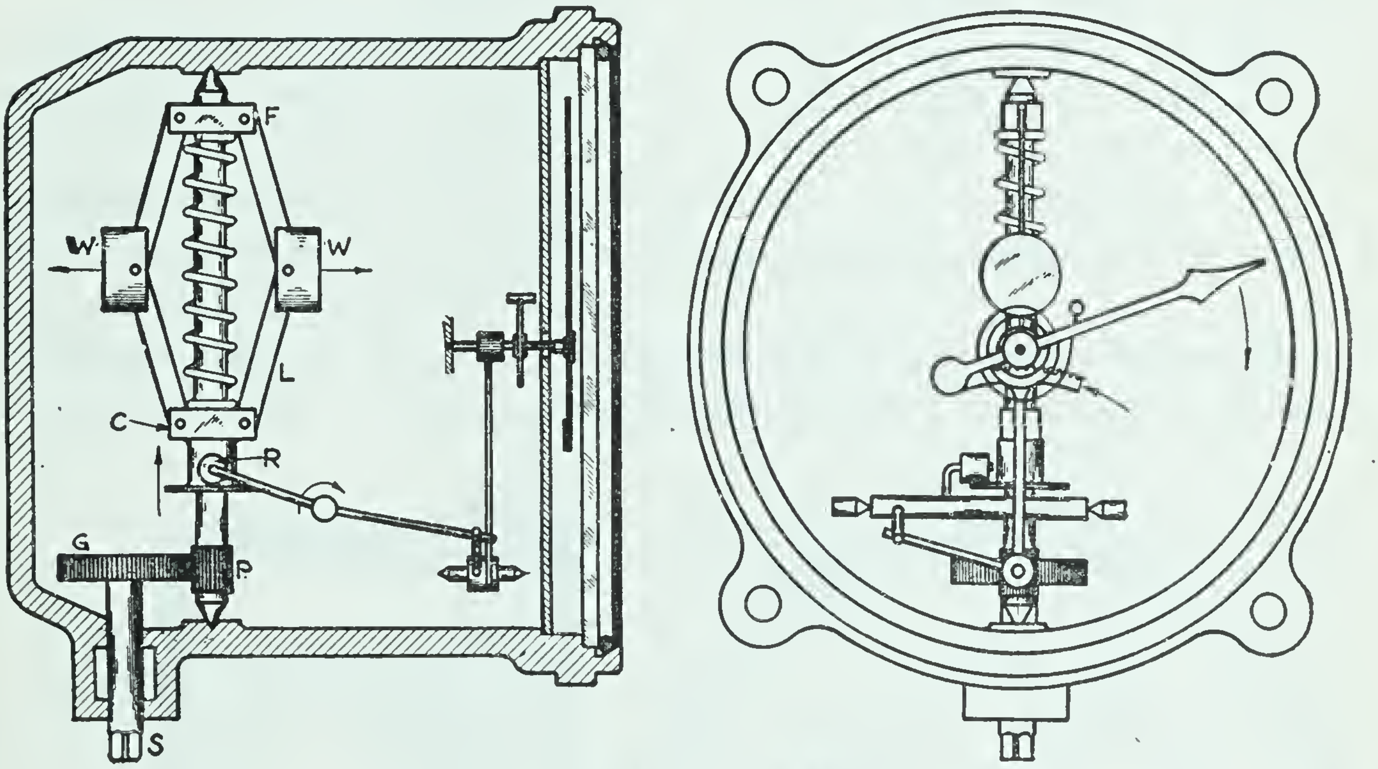
The two accompanying diagrams (Fig. 176) show front and side views of a *centrifugal* tachometer, which, if in good condition, will indicate the engine speed with an accuracy of plus or minus 25 r.p.m.

The tachometer is rotated by a flexible cable connected to the engine and operates on the same principle as the fly-ball governor commonly used on large stationary engines. The weights (Fig. 176) tend to move away from the center of rotation because of centrifugal force. The faster the spindle is turned, the greater the centrifugal force exerted by the weights.

The upper collar (F) is fixed to the shaft, but the lower collar (C) is free to slide up and down on the shaft. The centrifugal force of the weights pulls the lower collar (C) upward against the tension of a carefully calibrated control spring. By means of a system of levers, the up-and-down motion of the collar is transferred to the back-and-forth motion of the indicator pointer. A hair spring keeps the pointer under a slight tension, which prevents any abnormal fluctuations of the pointer.

Another type of tachometer is the *voltmeter* type, which consists mainly of a small generator, driven by the engine. The faster the generator turns, the higher the voltage it develops. The generator is connected by means of wires to a voltmeter mounted on the instrument panel. The voltmeter is calibrated to indicate r.p.m. instead of volts, since the one is directly proportional to the other.

Still another type of tachometer is the *synchronous-motor* type. A small generator driven by the engine is connected by wires to a small motor mounted in the tachometer case on the instrument panel. The motor is so constructed that it always turns at the same speed as does the generator and, by means of a magnetic device, indicates the r.p.m. of the engine. This type of instrument usually will indicate the engine r.p.m. more accurately than will the centrifugal type.



Courtesy Pioneer Instrument Division Bendix Aviation Corporation

Fig. 176. A centrifugal tachometer

The bourdon tube. Most people are familiar with the carnival "snake" (Fig. 177) so often used at New Year's Eve celebrations. By blowing on one end of a coiled paper tube, the tube is caused to unroll and become straight. This is the principle involved in the operation of the bourdon tube which makes possible the oil-pressure gauge, oil-temperature gauge, liquid-temperature gauge, and manifold-pressure gauge commonly used on airplanes. The bourdon tube, which is filled with a liquid or a gas, consists of a hollow tube of flat, oval cross section, sealed at one end and bent into an arc greater than 180°. When the fluid pressure within the tube is greater than the pressure on the outside, the tube tends to change from an oval cross section to a circular one. This in turn tends of equalize the length of the inside and outside walls of the tube and results in a straightening of the tube. The greater the pressure in the tube, the more nearly straight it will become.

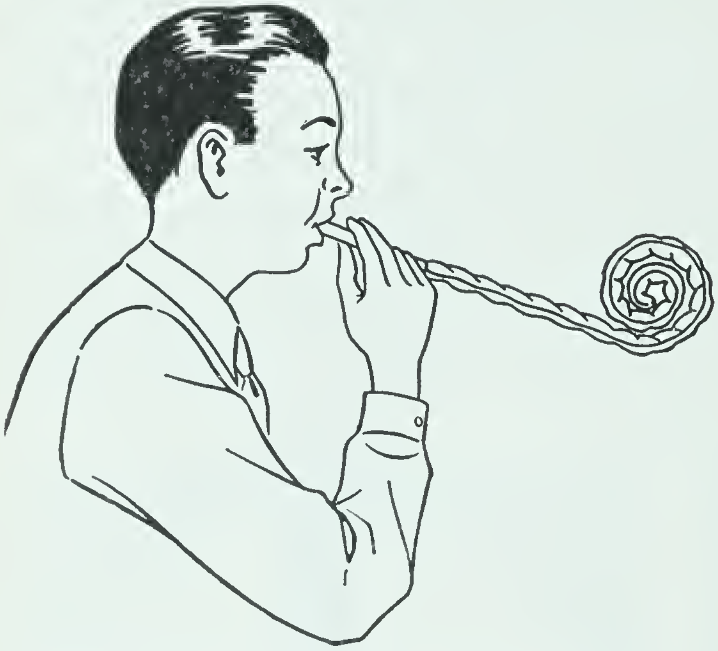
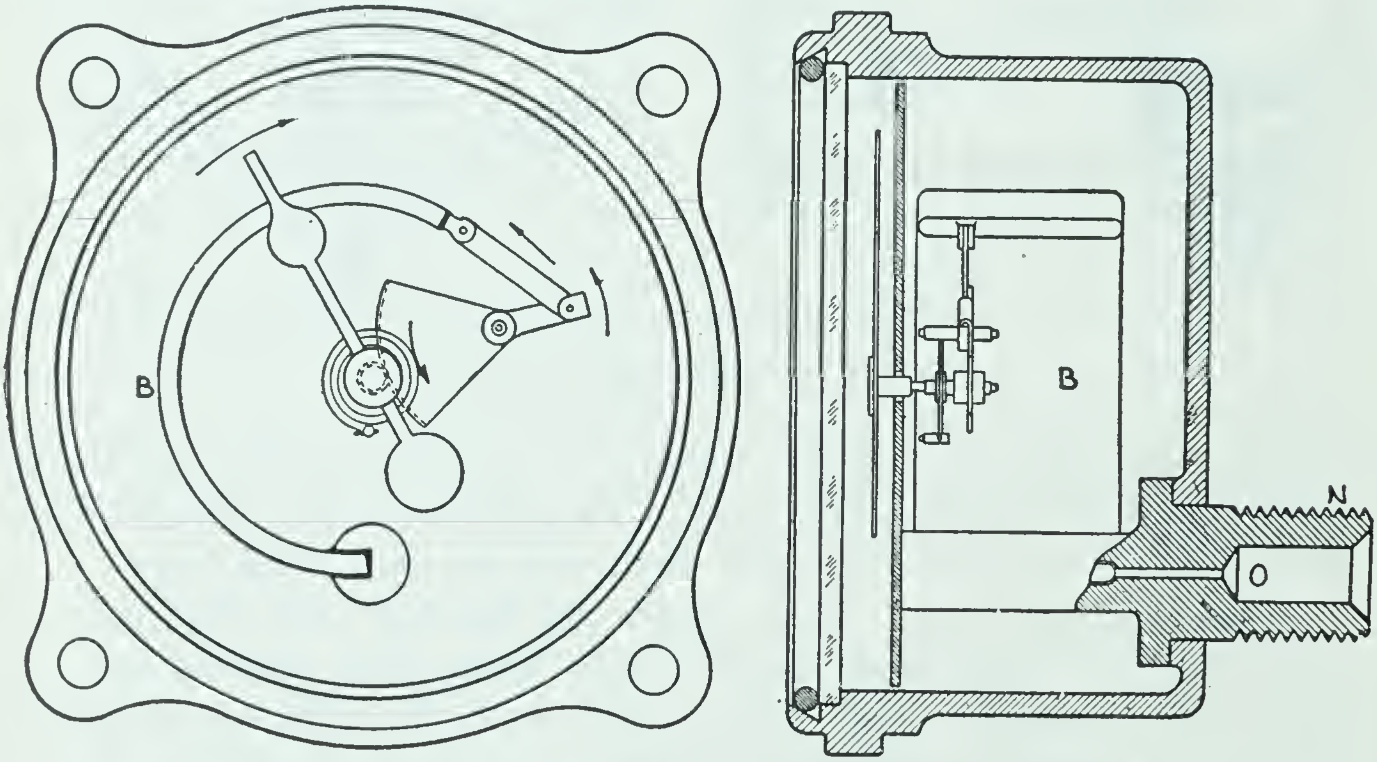


Fig. 177. The bourdon-tube principle

Oil-pressure and fuel-pressure gauges utilize the bourdon tube. The oil or gasoline forced into the tube causes it to straighten. The closed end of the tube is free to move and is connected to a lever system that operates the indicator pointer. Figure 178 shows front and side views of a bourdon-tube pressure gauge and illustrates the connections between the tube and the pointer. The letter (o) in the figure indicates the point at which the fluid is introduced into the tube.



Courtesy Pioneer Instrument Division Bendix Aviation Corporation

Fig. 178. The bourdon-tube pressure gauge

A low oil pressure may indicate any of the following conditions, each of which is serious: (1) oil temperature too high, (2) oil viscosity too low, (3) defective gauge, (4) worn or defective pump, (5) pressure-relief valve in oil pump sticking open, (6) pressure-lubricated bearings worn, (7) a plug out of the pressure system, or (8) exhausted oil supply.

On the other hand, too high an oil pressure may indicate: (1) that the oil pressure relief spring tension (in oil pump) is too great, (2) that the pressure gauge is defective, (3) that the oil temperature is too low, or (4) that the oil viscosity is too high.

Oil and liquid thermometers. Glass thermometers are adaptable to the home or to the laboratory, but there is no place for them in an airplane engine. Something more rugged and more easily read is required. As a result, the bourdon tube is utilized as a *pressure* thermometer. Pressure thermometers are of two types, the *vapor-pressure* type and the *liquid-filled* type. The liquid-filled type relies on the expansion of an enclosed liquid when heated and is essentially a volume thermometer rather than a pressure thermometer. For this reason the liquid cannot come directly from the oil pressure lines, since the pressure from the oil pump would influence the temperature reading. Alcohol and xylene are liquids commonly used and are enclosed in bulbs, with tubes leading to the temperature gauges. The bulb is usually mounted in the oil-discharge line so that the temperature of the oil as it leaves the engine will be indicated. Since the change in volume is slight, the bourdon tube (Fig. 179) is usually in the form of a spiral of several turns, which tends to give large deflection for small volume changes. Errors caused by variations in cockpit temperatures are prevented by a special coil made of two metals. A rise in temperature in the cockpit tends to straighten the bourdon tube and turn the indicator. The bimetal coil, exposed to the same temperature, lengthens exactly the same amount and relieves the tension on the indicator. The following diagram (Fig. 179 *a*) illustrates the arrangement of the bourdon tube, the indicator, and the compensating coil.

The *vapor-pressure* thermometer (Fig. 179 *b*) has a bulb and tube arrangement similar to that of the liquid-filled thermometer. However, the bulb is only partly filled with liquid (usually methyl chloride), and the tube and remainder of the bulb are filled with the vapor of the liquid. The methyl chloride is a volatile liquid whose vapor pressure at its surface in the bulb is the operating pressure.

The vapor pressure is transmitted to the bourdon tube through a copper tube having a very small cross section. Because of its simpler construction, the vapor-pressure thermometer is more popular than the liquid-filled type.

If an engine is liquid-cooled, it is a common practice to use a cooling-fluid thermometer and omit the oil thermometer. Cooling-fluid thermometers used in airplanes are exactly like oil thermometers. The bulb of the thermometer (liquid-filled or vapor-pressure type) is usually mounted either in the expansion tank or in the line to the radiator in order that it will indicate the highest temperature of the cooling system.

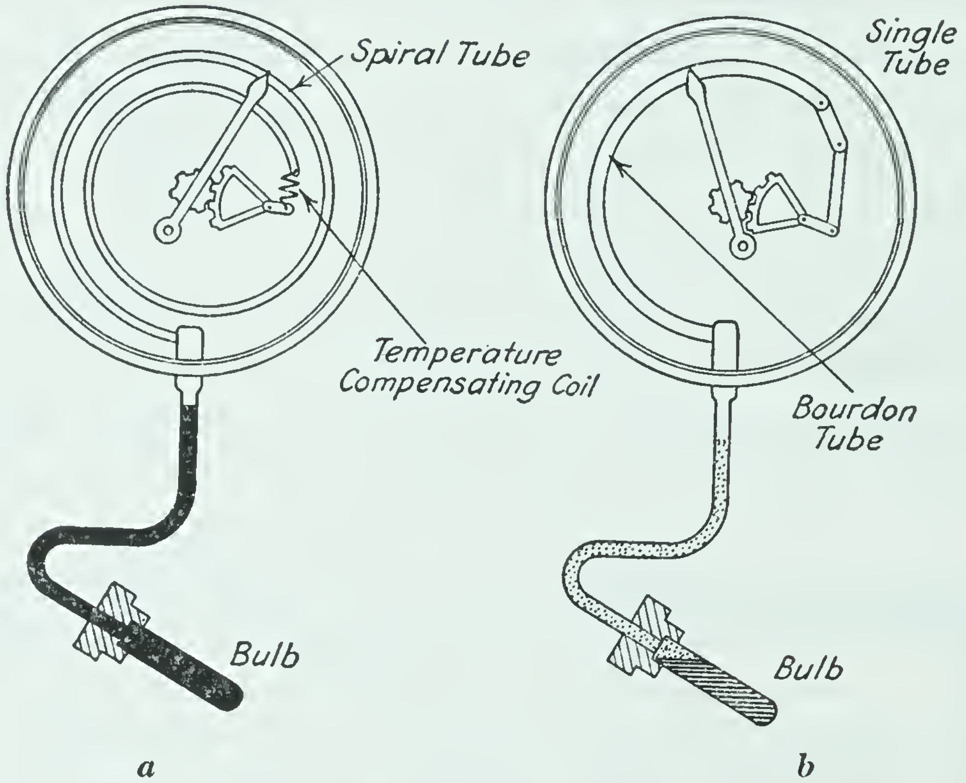


Fig. 179 *a*. Liquid-filled thermometer. *b*. Vapor-pressure thermometer

Overheating of a liquid-cooled engine may be due to an insufficient supply of cooling liquid, a worn or broken circulating pump, clogged radiator or hose connections, or may be falsely indicated by a defective temperature gauge. In any event, the pilot should make an immediate check to determine the cause and then remedy the situation.

Excessive oil temperature may be due to an insufficient oil-cooling capacity, an insufficient oil supply, diluted or contaminated oil, the improper grade or viscosity of oil, or prolonged overheating of the engine. Here also the necessity for an immediate check and remedy is apparent.

Manifold-pressure gauge. The manifold-pressure gauge vital to supercharged engines may be of two different types. Most manifold-pressure gauges utilize a very sensitive bourdon tube, the action of which has already been described. The other type uses an *elastic diaphragm,* similar to the diaphragm in an aneroid barometer.

Figure 180 illustrates the diaphragm element. The gas enters through the opening and then exerts pressure on the diaphragm This diaphragm is corrugated in concentric circles to increase its elasticity. The gas pressure forces the diaphragm outward against the pressure of the coiled spring, which is carefully calibrated. By means of a system of levers the pressure is transmitted to the indicator pointer.

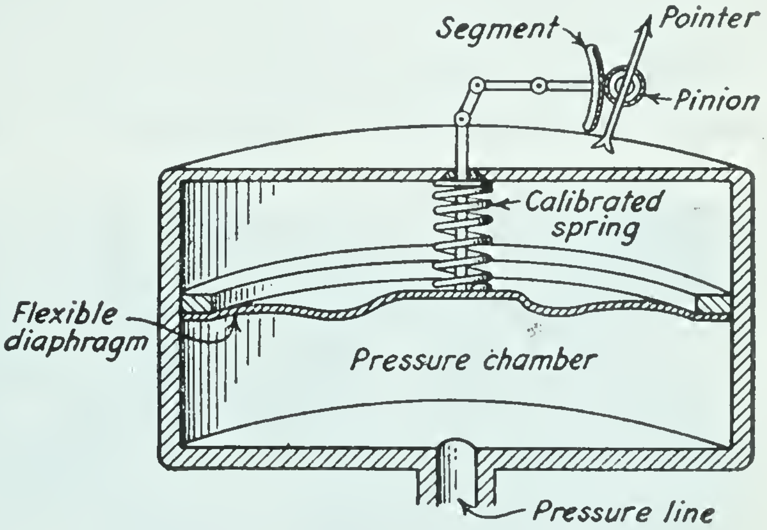


Fig. 180. Single diaphragm element in manifold pressure gauge

Figure 181 shows still another diaphragm element, in which two diaphragms are sealed together to form a capsule. The gas pressure is introduced inside the capsule and causes it to expand. This expansion results in movement of the pointer. A calibrated spring is sometimes introduced within the capsule, and the capsule expands against the tension of the spring.

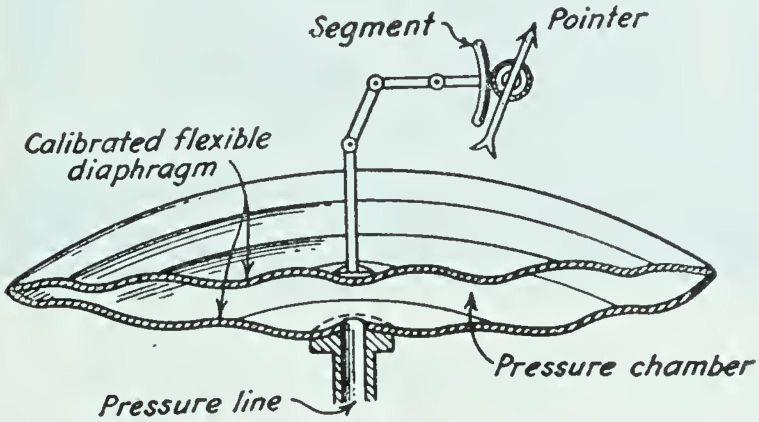
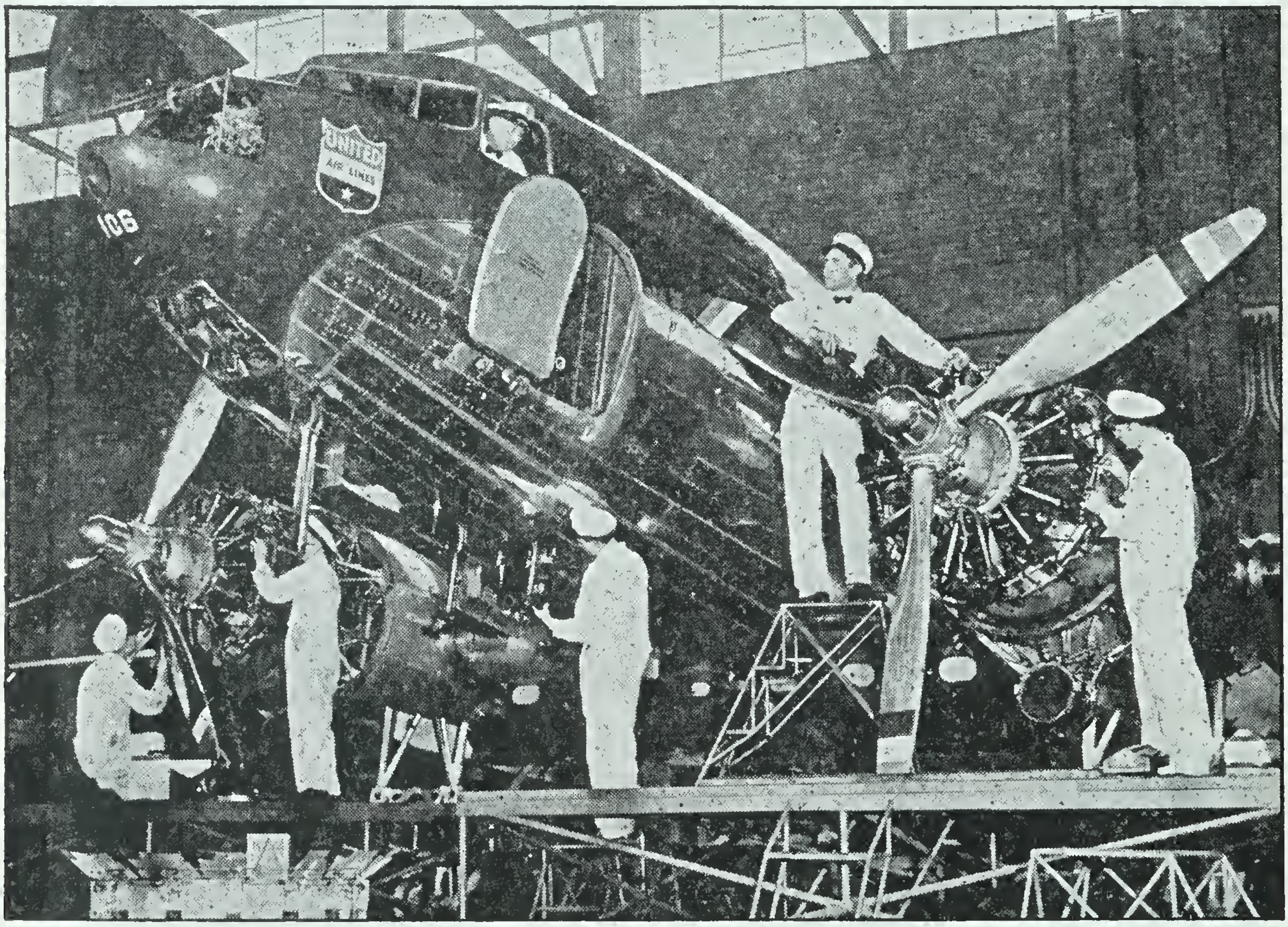


Fig. 181. Double diaphragm element in manifold pressure gauge

Periodic engine checkups and overhauls. All aircraft engines should be checked at regular intervals. These checks include: (1) a daily engine check before each flight, (2) an inspection after each 10, 20, 25, 50, or 100 hours of flight, depending upon the size, power output, and design of the engine, and (3) a periodic overhaul. In addition, the Civil Aeronautics Administration requires that a certified aircraft have a periodic inspection by a certified mechanic after every 100 hours of flying time.

Overhaul is classified as (1) top overhaul, and (2) major overhaul. *Top overhaul* consists of removal, inspection, reconditioning, and reinstallation of the cylinder and piston assemblies. A *major overhaul* involves the dismantling of the entire engine and all external attachments. The periods at which major reconditioning becomes necessary vary from approximately 350 to 800 hours of flight, depending on the engine and operating conditions.



Courtesy United Air Lines

Fig. 182. A crew of mechanics gives a typical check to a Mainliner

Large commercial airlines keep a very accurate record of the number of hours their engines operate and never allow them to run longer than the specified time between overhauls. In fact, the Civil Aeronautics Administration requires every owner of a certified aircraft to maintain (1) an aircraft log book, (2) an engine log book, and (3) an aircraft operation record. Thus all airplane engine operation time, all inspections, all overhauls, all repairs and alterations, and all breakdowns or accidents are on record for *all certified aircraft.*

Exercise 34. Prepare a report on the cylinder-head temperature gauge used in supercharged radial engines.

APPLICATION ACTIVITIES

1. Make a list of conditions which might account for the failure of an airplane engine to start when cranked.

2. Make a list of reasons for warming up an engine before a take off.

3. Explain why an airplane engine sometimes fails to stop when the ignition switch is turned off.

4. How would you explain each of the following if you were a passenger flying at 20,000 feet altitude in an airplane with a supercharged engine?

(*a*) Too high an oil pressure
(*b*) Slowing down of the engine
(*c*) Failure of the engine
(*d*) Detonation
(*e*) Too high an engine operating temperature
(*f*) Excessive engine vibration
(*g*) Failure of engine to develop full power

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UNIT V

AIRCRAFT COMMUNICATIONS

Exploratory Activities

1. Make a list of important discoveries or inventions which have contributed to the development of modern communication systems.

2. Make a list of ways in which energy can be transmitted from one point to another.

3. Explain the reason for the following: (*a*) A group of soldiers marching down the road is usually given the order to break step upon approaching a bridge. (*b*) It is possible for music to cause dishes or other objects in the room to rattle. (*c*) A swimmer walks to the end of a diving board and jumps up and down several times before he dives. (*d*) In order to operate a playground swing with best results, a force must be applied at proper intervals.

4. Why is it necessary that radio-transmitting stations be licensed by the government?

5. In general, why do higher-priced radio receivers employ more tubes than low-priced receivers?

6. How is it possible for an airplane pilot to steer a direct course between two cities even though he is not able to see landmarks along the way?

Overview

The coördination of any extensive system involving the rapid transportation of merchandise or persons involves the constant use of an equally extensive and even more rapid system of communications. During that period in the history of American enterprise which was marked by the westward extension of existing railroad systems, telegraph lines were constructed to parallel the new steel highways and furnish the speedy means of communication considered to be essential to railroad efficiency.

With the coming of the automobile and its widespread use as a means of flexible private and public transportation, the need for equally adaptable methods of rapid communication was intensified. This need was met in large measure by the telephone and by the construction of telephone lines, which not only spread a network over the denser areas of population but also extended to many of the most remote outposts of civilization.

Within the memory of even comparatively young men and women the airplane has developed into one of our most efficient methods of transportation. Parallel to the perfection and general acceptance of the airplane, the radio has become a universal means of almost instantaneous communication with all parts of the world. While the telegraph and telephone are extensively used in coördinating public and private transportation by airplane, it is the radio that is particularly adapted to the needs of air travel. The modern airplane flies long distances between ground stations. While a plane is in the air the telephone and telegraph cannot be used, but the radio can. It is inevitable, therefore, that the radio should contribute immeasurably to the safety and convenience of air travel.

How the voice can be transmitted hundreds of miles through space without the aid of wires remains a mystery to most people. How invisible radio waves may be used to mark the highways of the air; or to enable a pilot to fly a direct route between two cities while the surface of the earth is obscured by clouds; or to find his way "home" after becoming temporarily lost is still less generally known.

In this unit you will be given an opportunity to learn the answers to these questions and other interesting and sometimes perplexing problems associated with radio communication as it is used in the aeronautics industry. Since radio waves are much more readily understood if one is familiar with certain principles associated with sound waves, the discussion of radio is preceded by a discussion of communication by sound. The problems included in the unit are:

1. How have methods of communication been improved through discovery and invention?

2. How does a study of sound waves aid in the understanding of radio communication?

3. What are the mechanical and electrical principles involved in radio transmission and reception?

4. What applications of communication systems are important in aviation?

Problem 1. How have methods of communication been improved through discovery and invention?

Looking back on the history of the human race, we find several so-called ages: the Stone Age, the Iron Age, the Bronze Age. Future historians may record the present age as the Age of Science and Invention. Certainly, marvelous developments have come in recent years. In fact, the developments of the last hundred years far exceed the total scientific achievement of the human race previous to this time.

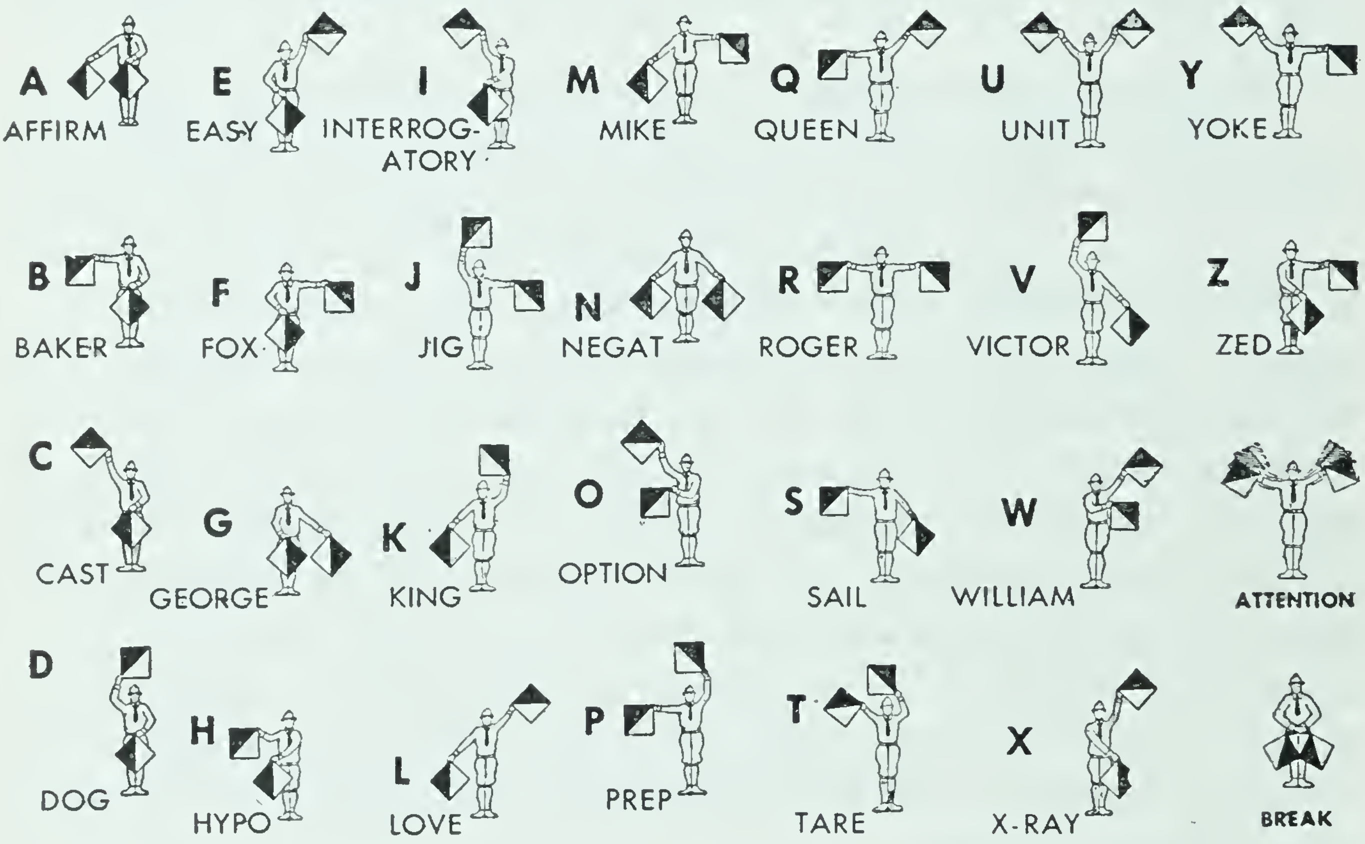
In order to appreciate this rapidly changing world, let us try to imagine how different things were when your parents were in school. This change becomes more striking if one tries to imagine the world one hundred years ago before the invention of the radio, the telephone, the telegraph, and many other devices now taken for granted.

Communication by sound. If we were to start at the beginning, we should find that primitive man probably communicated with his fellows by use of grunts and other vocal sounds. He could communicate by gesture and touch, but the combination of voice and ear was far more convenient and effective than other methods based on sight or touch alone. Vocal communication did not interfere with the use of the hands, eyes, or other members of the body. Moreover, communication by voice could be used where the speaker and hearer could not see each other. However, man could communicate by voice only as far as he could be heard. In order to communicate over greater distances, the voice could be directed by the hands or a horn. By placing the hand to the ear or by use of an ear trumpet, the distance could be further extended. Some early accounts tell of conversations carried on by use of horns and ear trumpets at a distance of a mile and a half.

One of the most interesting methods of communication was that used by the great Persian King Cyrus. Sentinels were set up at regular intervals within hearing of one another, and messages were shouted from one to the other. Imagine the number of men it would take to make a human telephone line between two cities and the resultant chances for misunderstanding and mistakes. By this method the news of the Massacre of the Romans at Orleans, 53 B.C., is said to have traveled by the human voice 160 miles in one day. This method of communication was used in some places until the Middle Ages.

The Greeks and Romans used relays of couriers to transmit messages. Each courier would run his route, then shout the message to the next runner. Later, messages written on pieces of stone, bark, or skin were passed from one runner to the next. The range of communication was greatly extended by use of sailing vessels on the sea and by horses and camels on land. It is interesting to note that after this means of overcoming distances had been developed, little improvement followed for hundreds of years. Julius Caesar could send a message with the same speed that was available to Napoleon 1700 years later.

Communication by sight. From the earliest time, man has yearned for some kind of instantaneous communication, especially in time of war. "Fire signals are a nuisance—you have to burn too many fires at once to let your allies know that sixteen ships are coming along the coast," complained one of the ancient Greeks, who proposed a complicated system of signals floating in large jars of water. There is no assurance, however, that the system ever worked. Since that time many attempts have been made to signal by arms, flags, and semaphores. Three brothers, Frenchmen by the name of Chappes, developed under war-time conditions a system of communication using

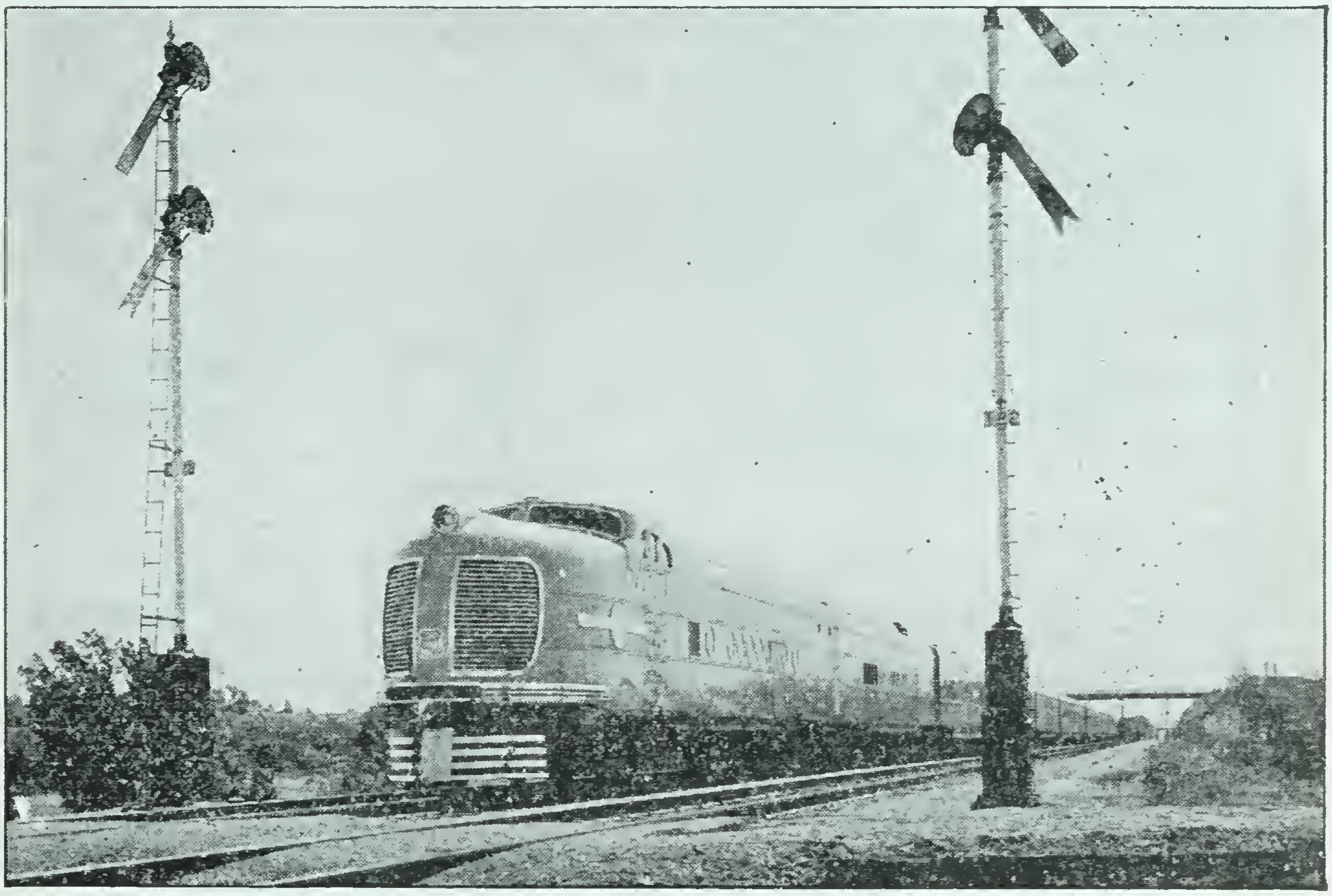


Courtesy American Radio Relay League

Fig. 183. The semaphore alphabet. A modern adaptation of an old principle.

the semaphore. At the end of the Napoleonic Era, there were 1112 miles of semaphore telegraph in France.

In Russia, Nicholas I, 1825-1855, developed a semaphore line connecting the important cities of Moscow, St. Petersburg, and Warsaw. At the same time, in America, several semaphore lines were built. One line between New York and Philadelphia worked for several years. In 1837 a line was proposed to connect Washington with New Orleans. It was thought that a message could travel the distance in one hour. Among objectors to the line was Samuel F. B. Morse, who contended that it would be unwise to complete the line as he had plans for a telegraph system using electricity which would work day or night and in any kind of weather.



Courtesy Union Pacific R. R.

Fig. 184. A modern semaphore system

Morse sent his first public message in 1844. In time, the electric telegraph with its advantages of speed and convenience replaced most semaphore systems. However, the idea of the semaphore has been retained and its used today by the railroad systems.

Communication by means of electric currents. The invention of a method of transmitting messages by means of an electric current conducted from one point to another through a wire, represented a milestone in the development of instantaneous communication. The application of this principle in the telegraph and later in the telephone has from the very beginning been inseparably related to the development of systems of rapid transportation. Even today, although the telegraph and telephone have been in many respects supplanted by the radio, these forms of communication are essential to the uninterrupted operation of land, sea, and air transportation.

The first patent for the telegraph was filed by Morse in 1837. Seven years later Morse succeeded in sending a code message from Washington, D. C., to Baltimore. This message marked the beginning of long-distance communication in the United States.

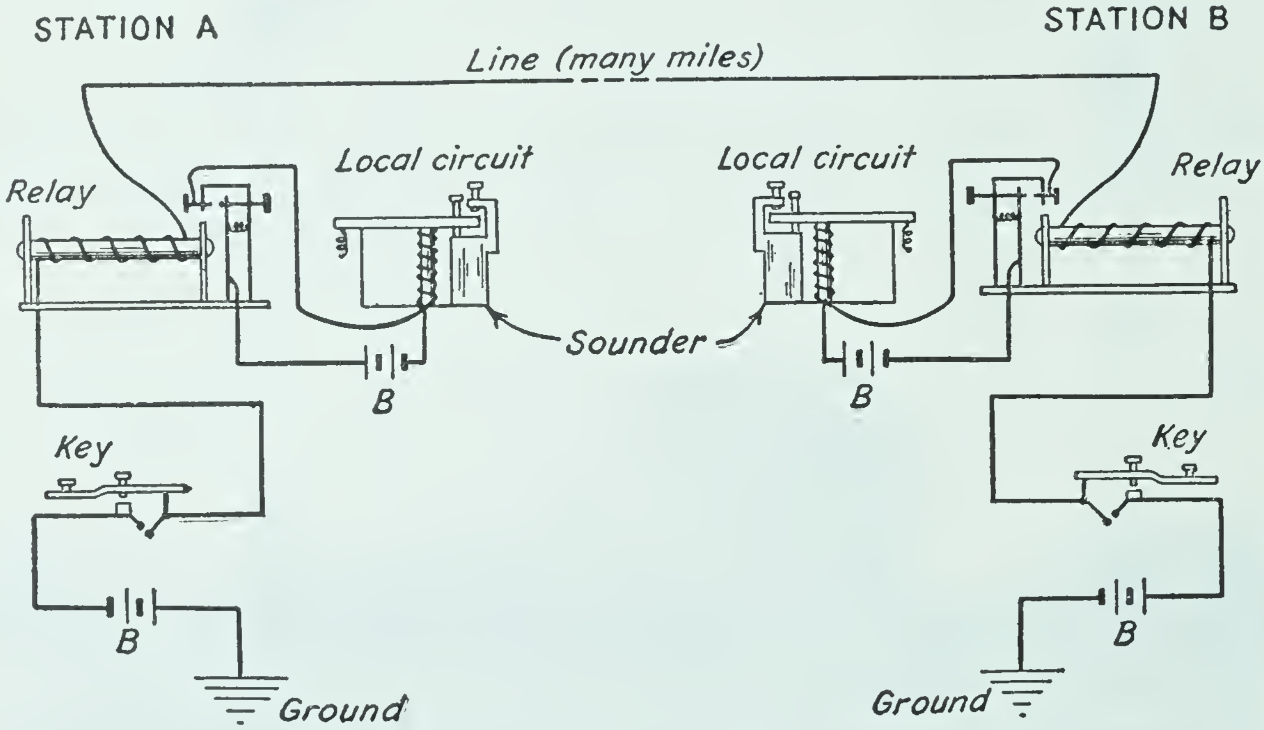
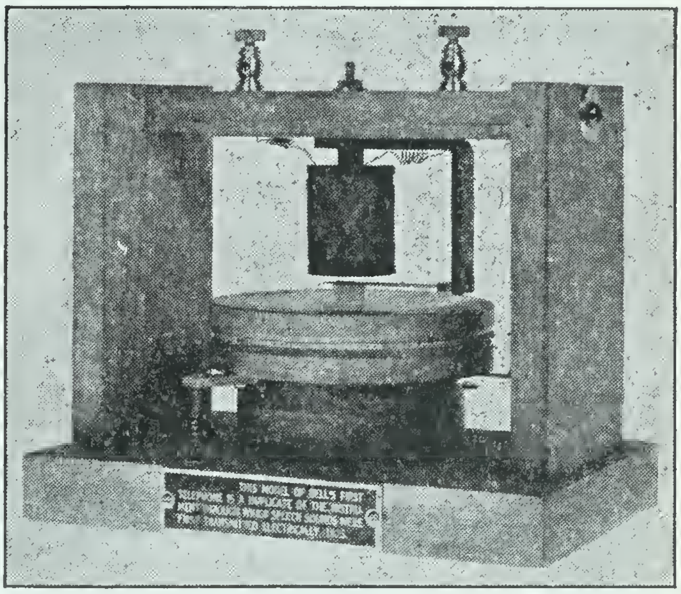


Fig. 185. The telegraph circuit

In its simplest form the telegraph consists of a key and a sounder located at each station on the line. The key is simply a device for opening and closing an electric circuit quickly and for permitting the current to flow whenever the key is not in use. The sounder employs the principle of the electromagnet in drawing an iron bar or armature down quite forcibly whenever current flows in the local circuit, thus producing a click which may be heard for a short distance. The relay which is placed in the line whenever messages are to travel long distances, also employs the principle of the electromagnet. Since its coils are wound with many turns of fine wire, it operates on a very small current and is used to open and close the sounder circuit. The operation of a telegraph circuit is best understood by reference to a circuit diagram.

In the diagram (Fig. 185), if it be assumed that the key at station *B* is closed, current will flow through both relays and the line whenever the key at station *A* is closed. The instant that this key is closed the electromagnets of both relays draw the armatures to them, thus closing both local circuits. This allows the sounding bars of both sounders to be attracted simultaneously, and clicks are heard at both stations. When the key at station *A* is opened, the springs break the contact at both relays simultaneously and both sounding bars spring back into place with audible clicks. By opening and closing the key at spaced intervals, code messages may be transmitted from station *A* to station *B*. When the operator at station *A* is through transmitting, he closes his key, thus making it possible for the operator at station *B* to acknowledge or reply to his message.



Courtesy Bell Telephone Laboratories

Fig. 186. Bell's original telephone through which, in 1875, speech sounds were first transmitted electrically

Laboratory Exercise 1. Set up a telegraph circuit as indicated in Figure 185 and transmit messages between stations.

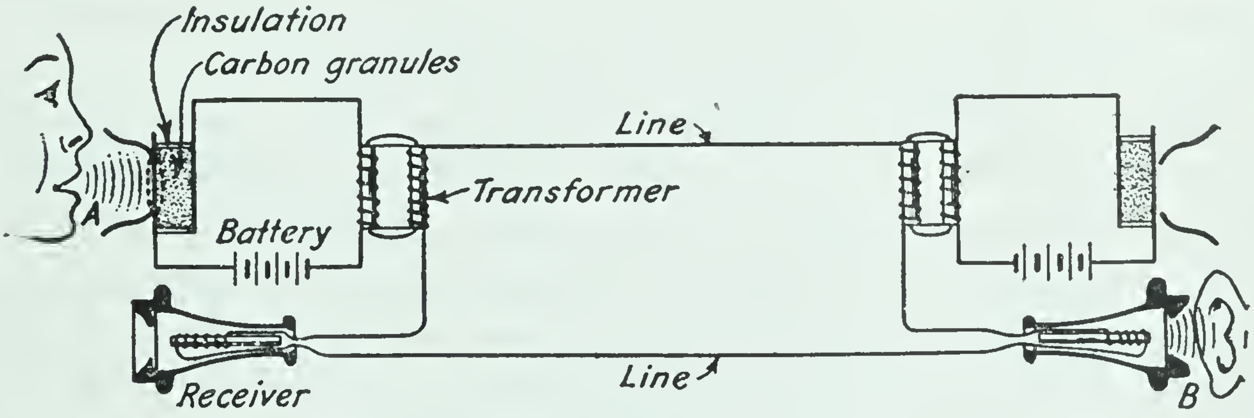


Fig. 187. The telephone circuit

The telephone was invented in 1875 by Alexander Graham Bell and improved by Edison in 1877. Like the telegraph, it employs the principle of the electromagnet. However, it represents a distinct improvement over the telegraph since it permits the reproduction at the receiving end of the line of the voice of the person transmitting the message.

The essential parts of a modern telephone are the transmitter and the receiver. The Edison transmitter is shown diagrammatically in Figure 187. Carbon granules offer resistance to the flow of an electric current which varies considerably with a slight change in the pressure to which these granules are subjected. As sound waves (condensations and rarefactions) strike the diaphragm at *A*, the pressure on the granules is varied in exact accord with the pressure variations of the waves. This procedure causes a corresponding variation in the resistance of the transmitter circuit and in the current flowing through the primary coil of the transformer. Variations in the primary coil produce similar variations in the induced current in the secondary coil and in the line.

The construction of the telephone receiver is shown diagrammatically in Figure 188. It consists of a permanent horseshoe magnet *M*, the ends of which are wrapped with many turns of fine wire forming a continuous circuit from one pole to the other. The force of the permanent magnet keeps the steel diaphragm *D* under constant slight tension. Since the wires forming the electromagnet are connected to the line, any variation in line current results in a variation of the magnet attraction for the receiver disk. Thus the disk is set into vibration in exact accord with sound waves impressed on the diaphragm of the transmitter at the other end of the line.

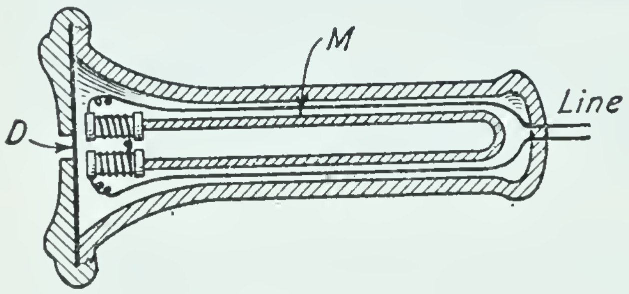


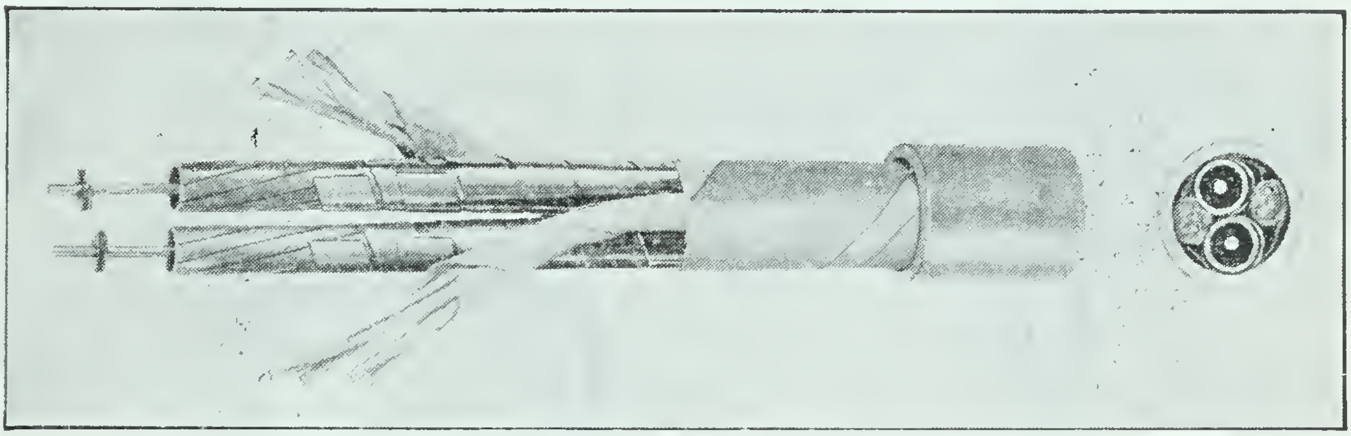
Fig. 188

While present-day telephone systems are much more complex than the preceding discussion would indicate, the fundamental principles are the same. However, one notable achievement of comparatively recent date seems worthy of mention. Modern engineering now makes it possible to transmit several different telephone and telegraph messages over the same wires simultaneously. A special cable recently developed is capable of transmitting 480 different messages at the same time. A second very welcome improvement involves the use of vacuum-tube amplifiers in long-distance telephone lines, thus making communication between widely separated points as easy and efficient as talking to a person in the next block.

Laboratory Exercise 2. Set up a telephone circuit as shown in Figure 187 and transmit messages from station to station.

Communication by radio. Few, if any, inventions have appealed to the general public as strongly as has radio. In a period of a few years we find general acceptance of radio as a means of entertainment and information.

While science does not believe in magic, the accomplishments of modern radio are little short of magic. By the turn of a knob or the push of a button we can select one of many programs coming from near or distant stations. By use of short waves, stations from distant countries may be heard. We talk of radio waves, yet few understand how these waves are able to carry the voice. This is understandable when we realize that we cannot see, hear, feel, taste, or smell radio waves.



Courtesy Bell Telephone Laboratories

Fig. 189. Coaxial cable, which will carry hundreds of messages on a single wire, and its surrounding tube. This type of cable will also carry television signals.

In order to know about the action of these invisible, intangible radio waves, we shall first study a wave motion that can be heard, felt, and made visible. What wave motion is it? You have guessed it—sound-wave motion.

Exercise 3. Make a list of the important inventions, machines, and related devices utilized in communications which have been invented within the last hundred years and are now in common use.

Exercise 4. How many important inventions utilized in communications are in use today that were invented more than a hundred years ago?

Exercise 5. List the methods of communication which were available to primitive man.

Exercise 6. What was the advantage of the electric telegraph over the earlier forms of communication?

Exercise 7. What disadvantage of the telegraph was overcome in the telephone?

Exercise 8. What are some of the advantages of radio communication over telephone communication?

Exercise 9. What are the disadvantages of radio communication?

Problem 2. How does the study of sound waves aid in the understanding of radio communication?

In attempting to use sound waves to explain radio waves we should seem to be in the position of the blind leading the blind. Sound waves and radio waves are both invisible. However, if one touches a sounding object such as a tuning fork, he recognizes a trembling motion which soon disappears with the sound. This vibrating motion of the tuning fork will cause a pith ball to bounce in a surprising manner when it touches the fork (Fig. 190). If the vibrating fork is touched to the surface of water, a spray of water usually appears at the end of the tuning fork because of the rapid motion of

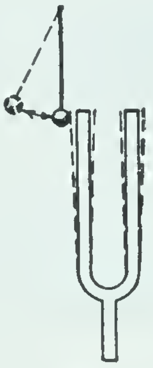


Fig. 190

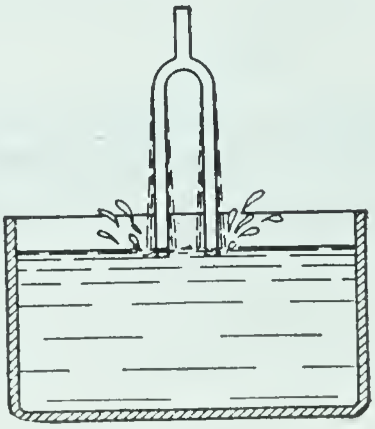


Fig. 191

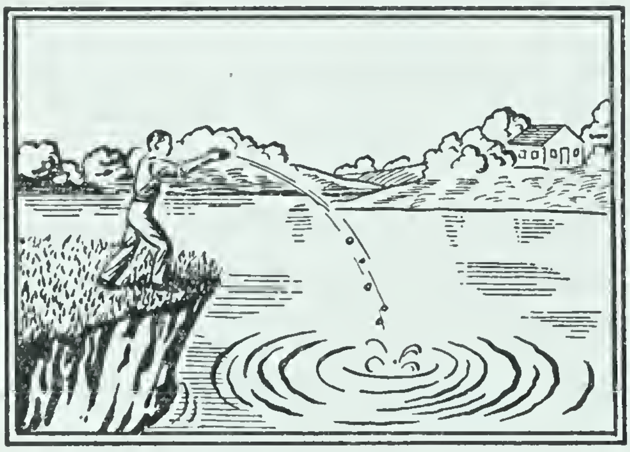


Fig. 192

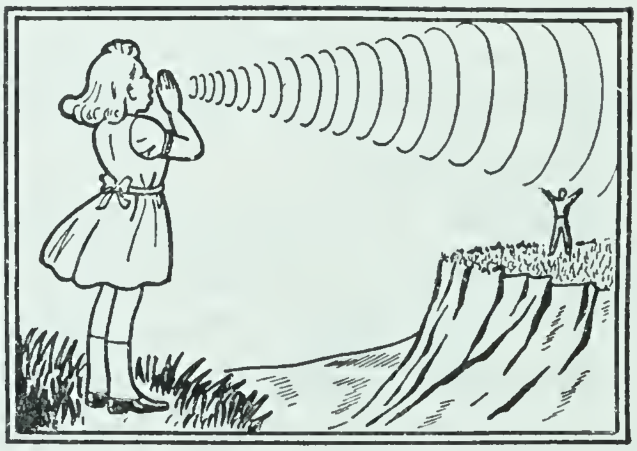


Fig. 193

the fork (Fig. 191). While water is set in motion by the tuning fork, the surface waves produced are not to be confused with sound waves. However, surface waves on water can help us to visualize how sound waves travel out from a source of disturbance (Figs. 192 and 193).

Surface waves of water tend to give two motions to a floating body. A cork not only moves up and down but it moves back and forth as the wave advances. The actual motion of a water particle as each wave passes is approximately circular. In a ripple the circular motion is small, but in an ocean wave the circle of motion is large (Fig. 194).

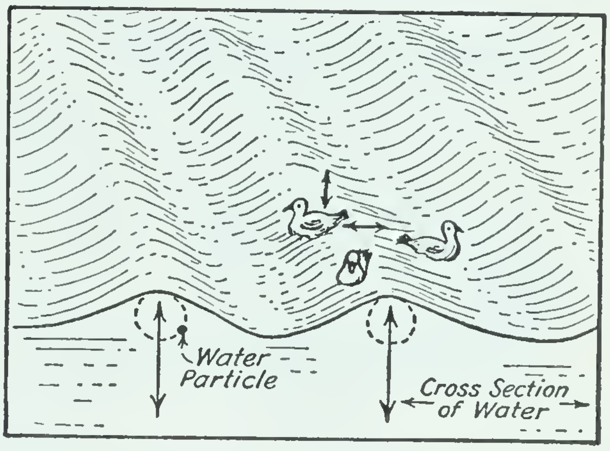


Fig. 194

Sound waves differ from water waves in that the motion of air particles is not circular but back and forth in the direction of the wave. This is called a longitudinal wave (Fig. 195). The vibrating tuning fork sets up alternate compressions and rarefactions which travel out as sound waves. When a wave reaches the eardrum, it gives the sensation of sound, but, if the motion is sufficiently strong, it may also affect the sense of touch. Deaf people can recognize strong sounds by the vibrations which these sounds set up in a light object such as a piece of paper. The actual back and forth distance the air particle moves in transmitting a sound wave is very small—about four thousandths (.004) of an inch for loud sounds or less than a billionth of an inch for weak sounds.

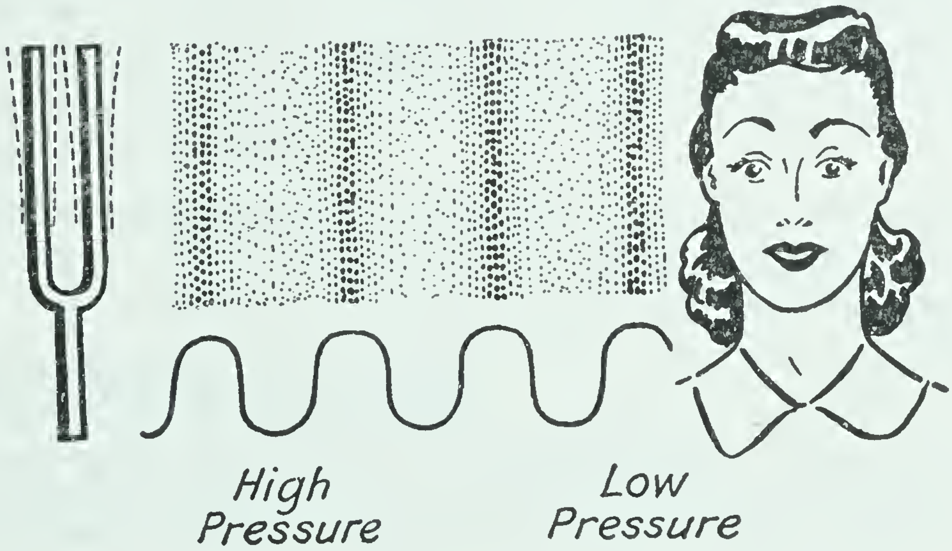


Fig. 195

A way of showing that energy can be transmitted from particle to particle without appreciable motion of the particles themselves is shown by the device in Figure 196. Several metal balls are suspended in line so that they just touch. When the ball at one end is pulled aside and allowed to fall, the ball at the opposite end flies off while the remaining balls show little displacement in transmitting the energy. Without air molecules or some other medium we could not hear a sound. The necessity of a material medium to transmit a sound from its source to the ear may be shown experimentally.

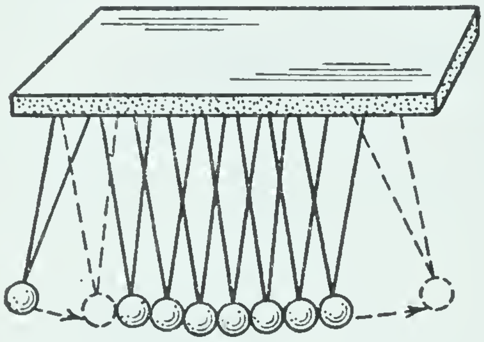


Fig. 196. Transmission of energy without appreciable motion

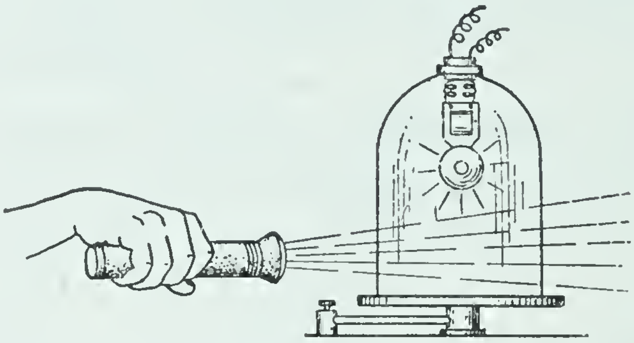


Fig. 197. Sound does not travel through a vacuum, but light does

An electric bell is placed in a bell jar which is connected to an air pump (Fig. 197). As the air is removed from the jar, the sound of the bell grows fainter, even though the clapper can be seen to strike the bell. As air is admitted to the jar, the sound becomes louder, thus indicating the need of a material medium to transmit sound.

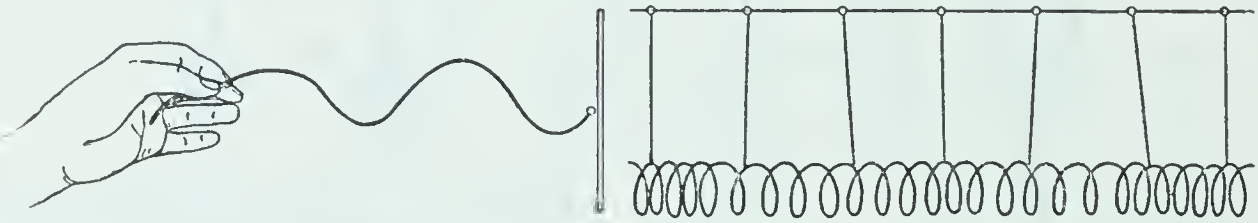


Fig. 198. *Left:* pattern of transverse light wave (piece of string) represented by moving hand up and down. *Right:* pattern of longitudinal sound wave (represented by a brass spring) such as that caused by clicking your finger nails.

However, light waves and radio waves do not need material media for transmission. They pass through a vacuum without difficulty. Radio waves and light waves differ from sound waves in type. A small length of rope and a brass spring can be used to aid in visualizing the transverse light wave and the longitudinal sound wave (Fig. 198).

Laboratory Exercise 10. *Equipment:* Sheet of paper, singing-flame apparatus, radio receiver with case removed.

a. Try singing a note while holding a paper in front of the mouth. Can you feel the paper moving?

b. With the singing flame in operation hold the paper at the lower end of the tube and compare the strength of vibration with that of the voice.

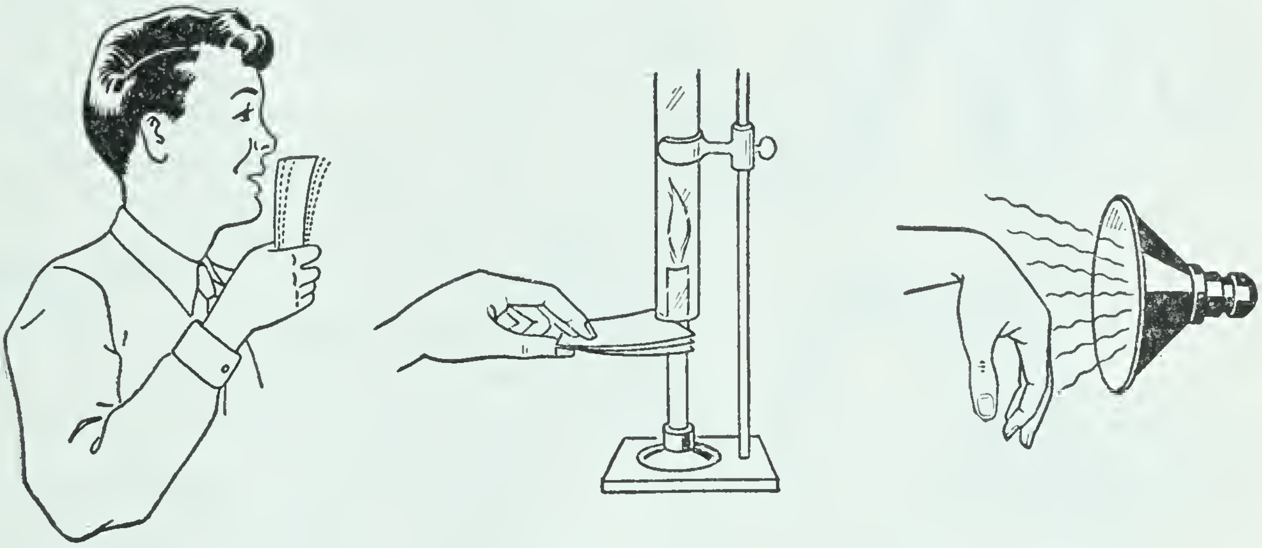


Fig. 199

c. Hold the back of the hand in front of a radio speaker while it is in operation. Note the sensation caused by the momentary winds produced by the sound waves.

Conduction of sound.

Laboratory Exercise 11. *Equipment:* Tuning fork, long wooden rod, pencil with eraser attached, two cans, and string.

a. Tie the middle of the string to the tuning fork. Hold the ends of the string to the ears while you swing the fork against the table. Remove the fingers from the ears and repeat the experiment. Is sound carried better through air or string? (Fig. 200.)

b. Place the end of a wooden rod to the end of a pen held in your teeth. Describe the sensation when the tuning fork is touched to the other end of the rod. Repeat the experiment with the rubber eraser of a pencil against the stick. Which material conducts sound best? (Fig. 201.)

c. Try to send sounds over a string or wire stretched between two coffee cans. Will the string or the wire carry your voice? (Fig. 201.)

Early experimenters observed that sound traveled through solids better than it did through air. Wheatstone, in 1821, produced what he called "the enchanted lyre." It was connected by a wooden rod with a piano which was in another room out of sight and hearing. Vibrations set up in the piano would travel to the lyre, causing it to give forth music much to the wonderment of the audience.

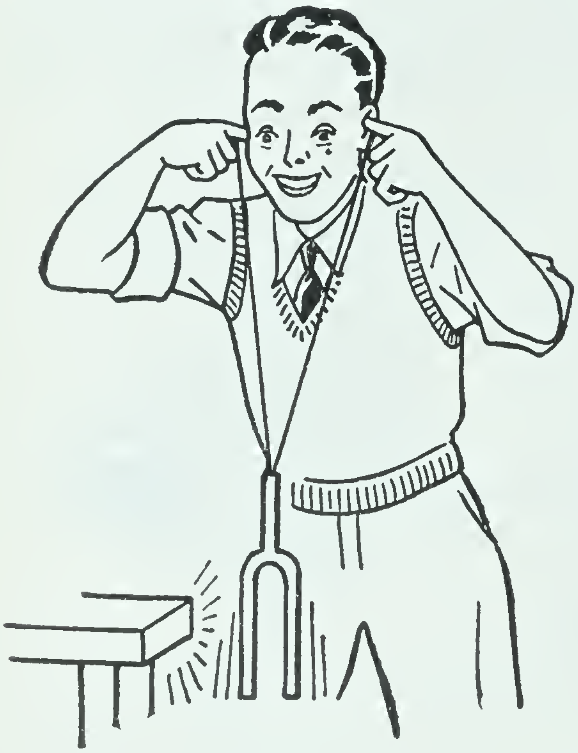


Fig. 200

After that came the "lovers' telephone" in which the voice was carried on a string or, better still, on a wire. Du Moncel, in 1879, wrote, "If we can believe some travelers, it has long been used in Spain for correspondence of lovers." The string telephone, as it is sometimes called, consists of a stretched membrane, each end of which is connected with a string or wire. One interesting account tells of a wire telephone of this type which operated for several years between homes separated by a distance of approximately one-half mile. It has long been known that certain materials such as earth, water, and metals are better conductors of sound that air.

Velocity of sound. The speed of sound depends upon the type of medium transmitting the sound. Liquids transmit sound waves faster than gases, and solids usually transmit sound waves faster than either liquids or gases. The speed of sound in air is 1088 feet per second at 32° F. while at 70° F. the speed increases to 1130 feet per second. The latter represents a speed of 770 miles per hour.

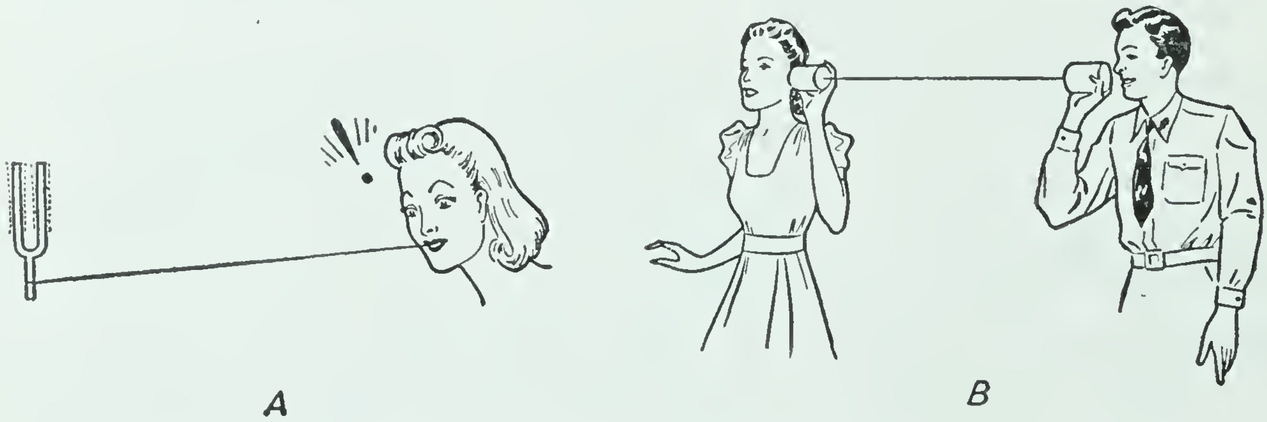
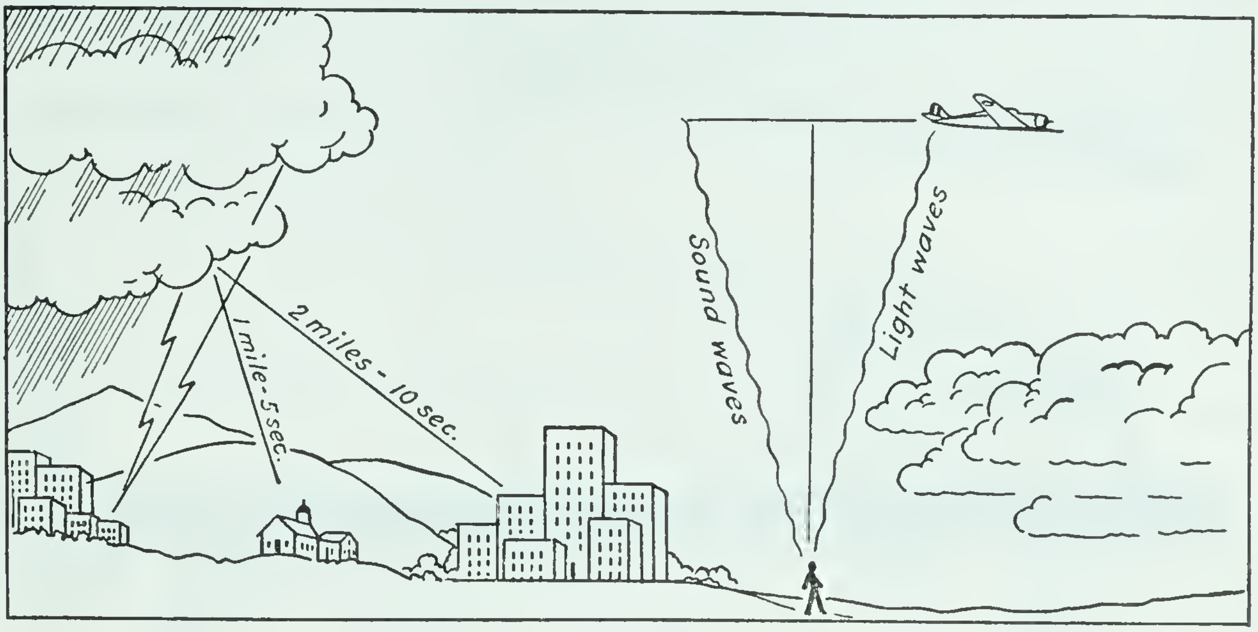


Fig. 201. Simple noise-transmitting device

Commonplace observation makes us aware of the difference in the speed of light and sound. If a locomotive is approximately a mile away, the steam from its whistle is seen about five seconds before the sound reaches the ear. The time elapsing between a flash of distant lightning and the resulting sound of thunder can be used to indicate the distance of a storm (Fig. 202).



	Temp.	Velocity - ft per sec.
Carbon dioxide	0°C.	846
Air	0°C.	1,088
Hydrogen	0°C.	4,165
Water	13°C.	4,728

	Velocity - ft. per sec.
Cork	1,640
Pine, lengthwise	10,900
Iron 20°C.	16,820
Class	19.690

Fig. 202

The location of large guns can be determined by the time it takes sound to reach two or more observation points. Because of the high speed of an airplane it may be far ahead of the direction indicated by the belated sound wave reaching the ear.

Laboratory Exercise 12. *Equipment:* Siren disk, rotor, card.

a. Hold a card against the teeth of a rotating siren disk. Is a musical note produced by the vibration of the card?

b. What change of sound takes place when the speed of the disk is increased or decreased?

c. Move the corner of the card to touch each of the various rows of holes. Explain why high and low notes are produced.

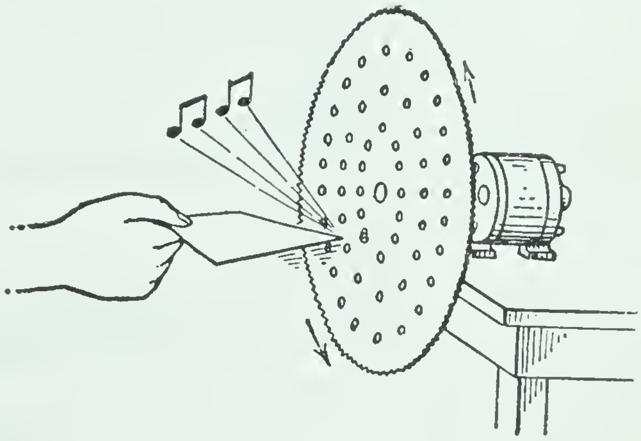
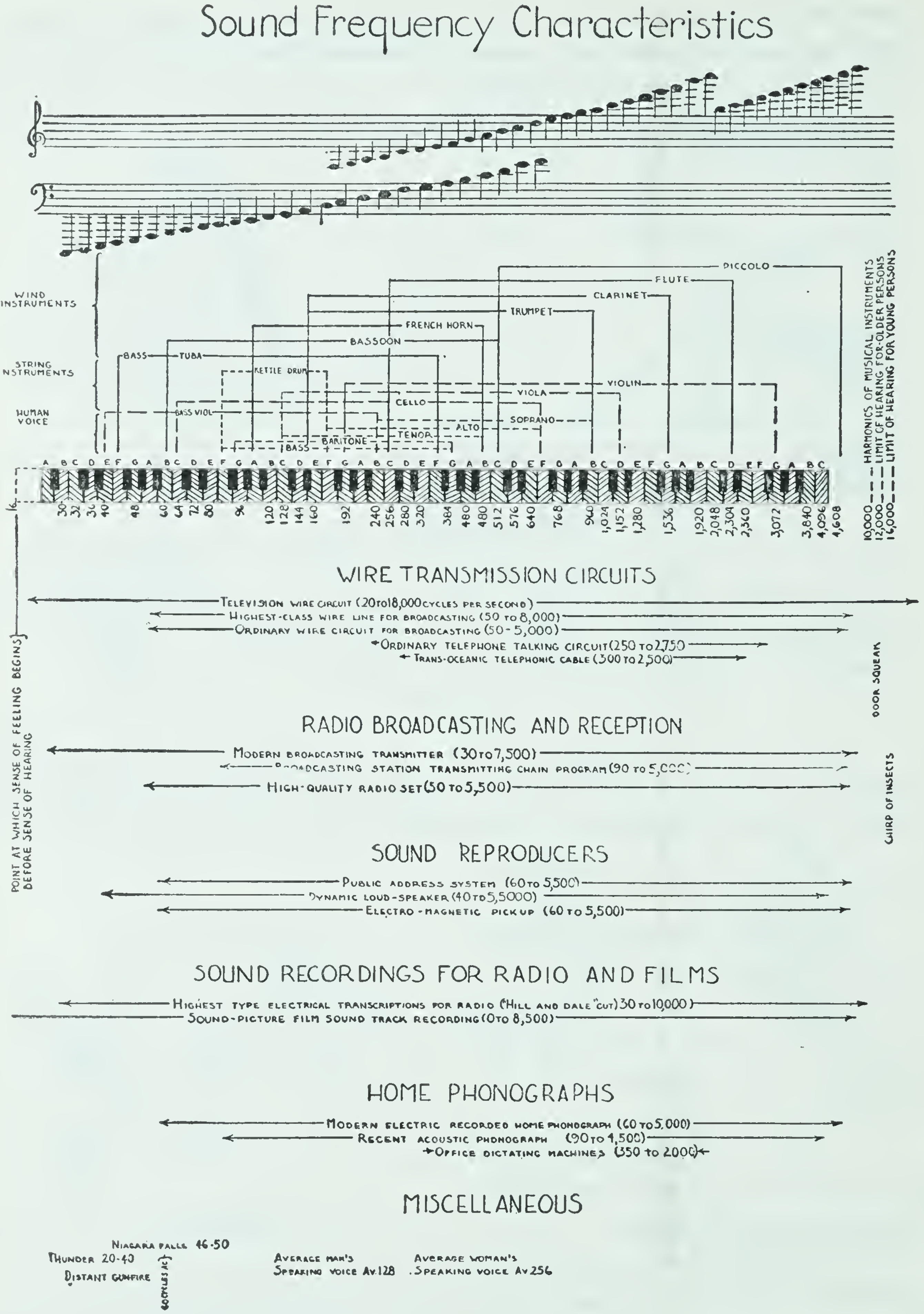


Fig. 203

When a card is held against the teeth of a rotating siren disk, the vibrating card sends out a musical note. By increasing the speed of the disk, the pitch of the note is increased; by reducing the speed,



Modified from Electronics

Fig. 204

the pitch of the note is made to fall. Evidently the pitch depends upon the number of vibrations per second. By moving the corner of the card over the different sets of holes in the disk, the notes of the musical scale or the major chord may be produced.

A man's voice has an average pitch of about 125 vibrations per second and a woman's voice is double this or an octave higher. Human voices differ in overtones or harmonics. These overtones may reach a frequency of about 10,000 vibrations per second. A comprehensive sound chart is shown in Figure 204.

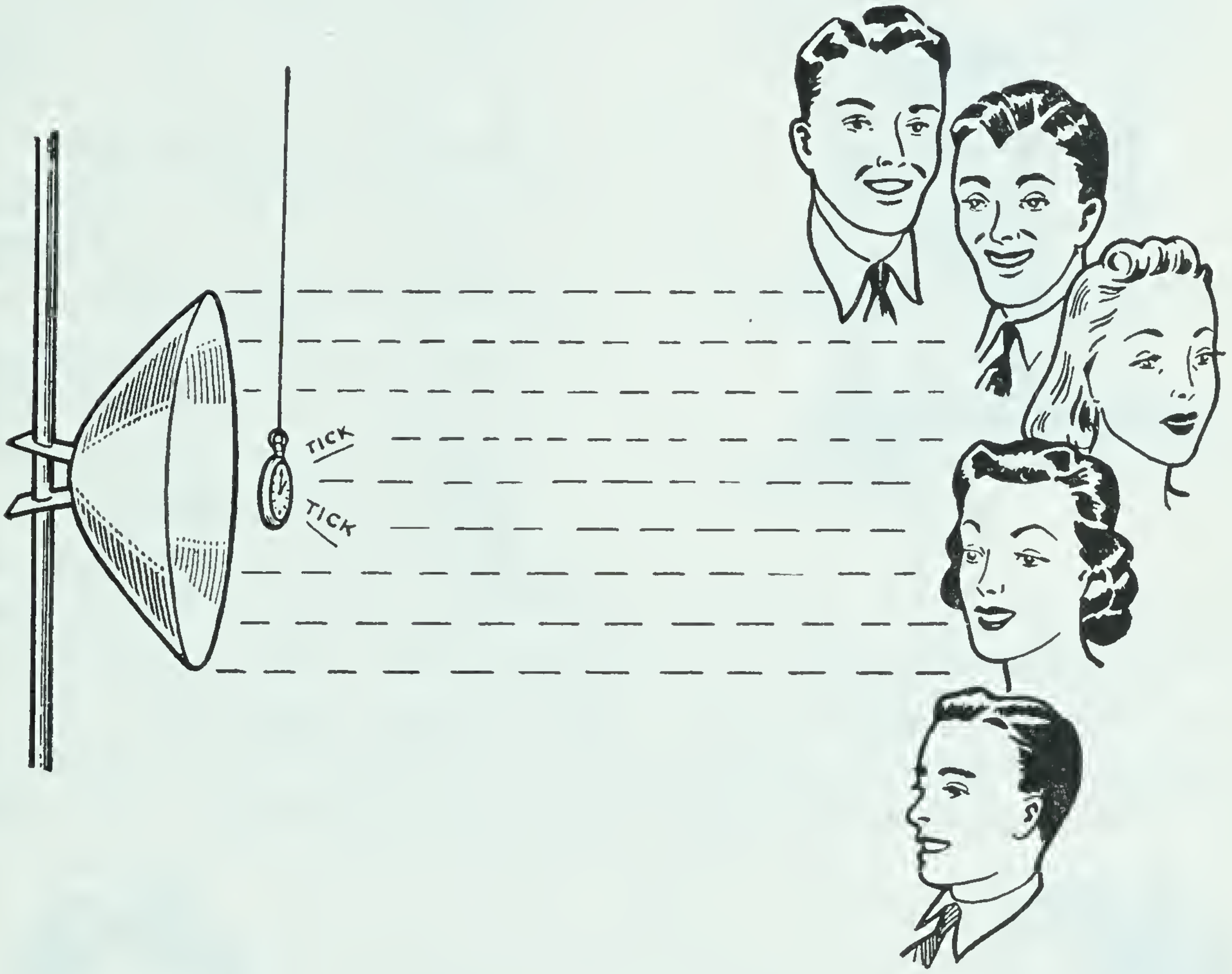


Fig. 205

Reflection of sound. When sound waves strike a wall, cliff, group of trees or any other obstacle, they are reflected and may return as an echo. Reflections from curved surfaces of a ceiling or wall make possible the whispering-gallery effects.

In the Hall of Statuary at the Capitol in Washington a whisper near one side may be heard distinctly at a point on the opposite side where the sound waves converge. The sound is not heard at other points in the room. In earlier days whispered conversations were said to have been unintentionally revealed to opposing politicians far across the room.

The Mormon Tabernacle at Salt Lake City is famous for its acoustic properties. The sound of a pin dropped near one end can be heard clearly at a distance of about 200 feet. Sound reflections on a smaller scale can be shown by holding a watch in front of a concave sound reflector. By turning the reflector from side to side, people in different parts of the room are able to hear the ticking of the watch (Fig. 205). A second sound reflector may be used to pick up sound too faint to be heard. The range can be greatly extended by use of a sensitive microphone (Fig. 206). Sound waves carried by a brass spring (Fig. 207) are reflected by the cans at each end of the string. A word shouted into one can will return as an echo which grows weaker with successive reflections.

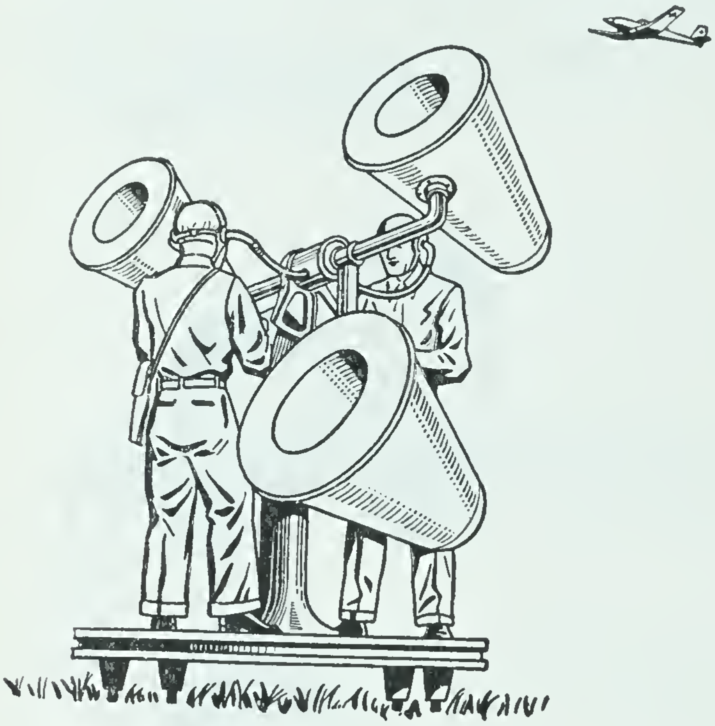


Fig. 206

Echoes go unnoticed in a small room because they return too soon for the ear to detect them as a separate sound. However if the sound is reflected from a distant wall (56 feet or more), it is recognized as a separate sound or echo. The time required for the echo to return can be used to gauge distance from an object. Some bats are thought to be guided by sounds reflected by nearby obstacles. The depth of

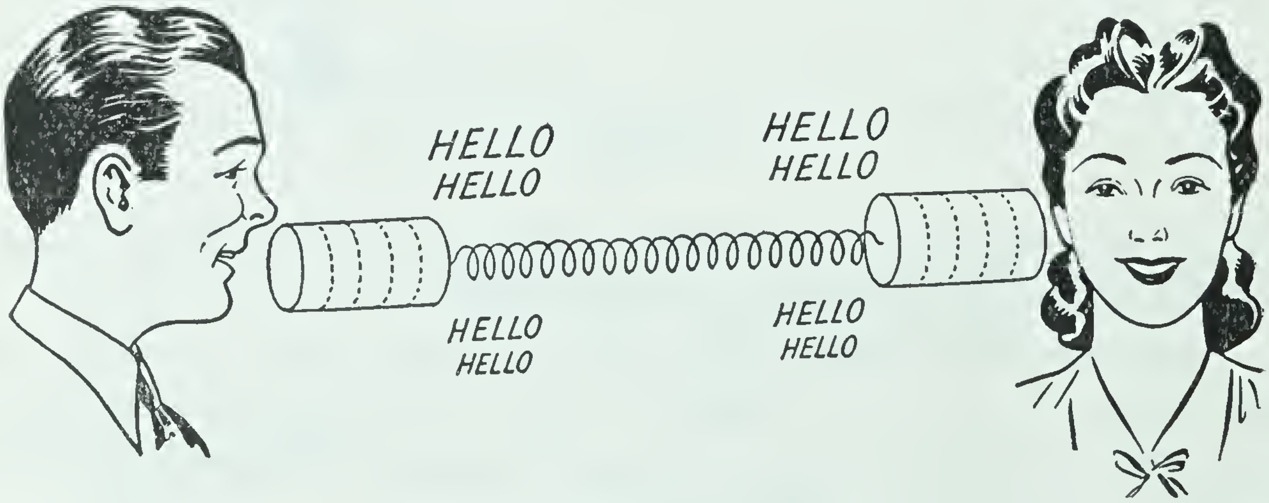


Fig. 207. Sound travels slowly in a spring. The reflected wave returns as an echo.

water may be obtained by directing a sound down into the water and measuring the time for its return (Fig. 208). The depth would be half the distance sound traveled during the round trip. In a similar manner, airplanes can use the time required for the return of a reflected radio wave to give their altitude (Fig. 209).

Sympathetic vibrations.

Laboratory Exercise 13. *Equipment:* Resonance boxes with two tuning forks at the same pitch, rubber mallet, and pith ball.

a. Strike tuning fork *A*. What happens to the pith ball touching fork *B?*

b. Substitute a fork of a different pitch in the resonator box *B* and repeat the experiment. Why are the results different?

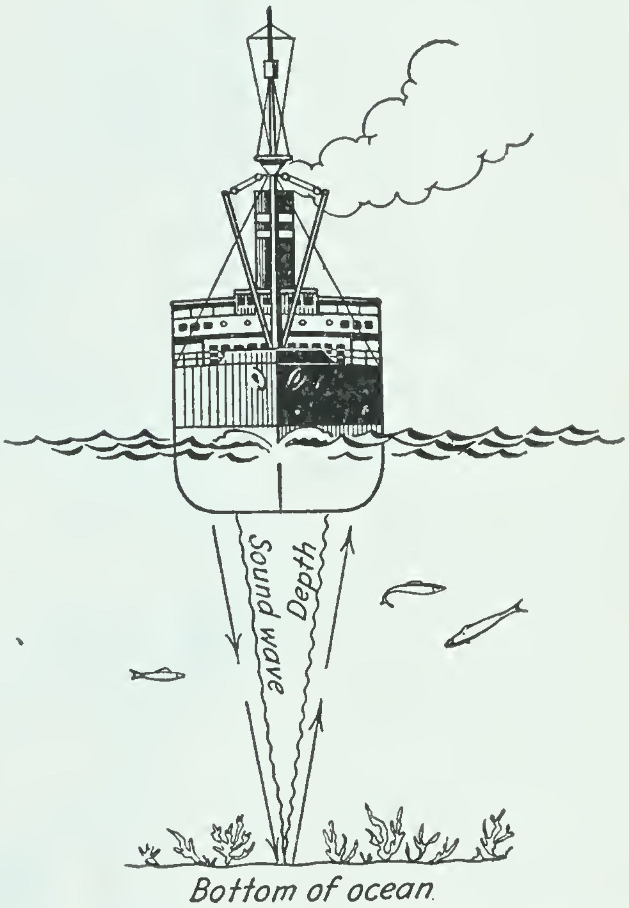


Fig. 208. The depth of water may be determined by reflected sound waves

The ability of sound waves to set up vibrations in a body placed at a distance may also be shown by resonance bars—namely bars that have the same natural period of vibration. When the bars are placed on opposite walls of the room and one is set into vibration by a rubber hammer, the other will start vibrating in sympathy because of the sound waves exerting pressure or push at just the right time (Fig. 210*b*). Other objects which are not so tuned do not show a noticeable vibration at this distance.

There are many examples of sympathetic vibrations. Musical instruments may respond to certain tones, and a goblet may be broken by a note of the right pitch. Sympathetic vibrations are not confined to sound waves but occur in connection with many moving objects. (See Figs. 211, 212, 213.) Some bridges have a natural period of vibration which responds to the footsteps of walking men. The steps of one man are not likely to produce dangerous vibration, but the footfalls of many marching men may set up vibrations which may cause the bridge to fall. Marching men are usually ordered to break step before crossing a bridge.

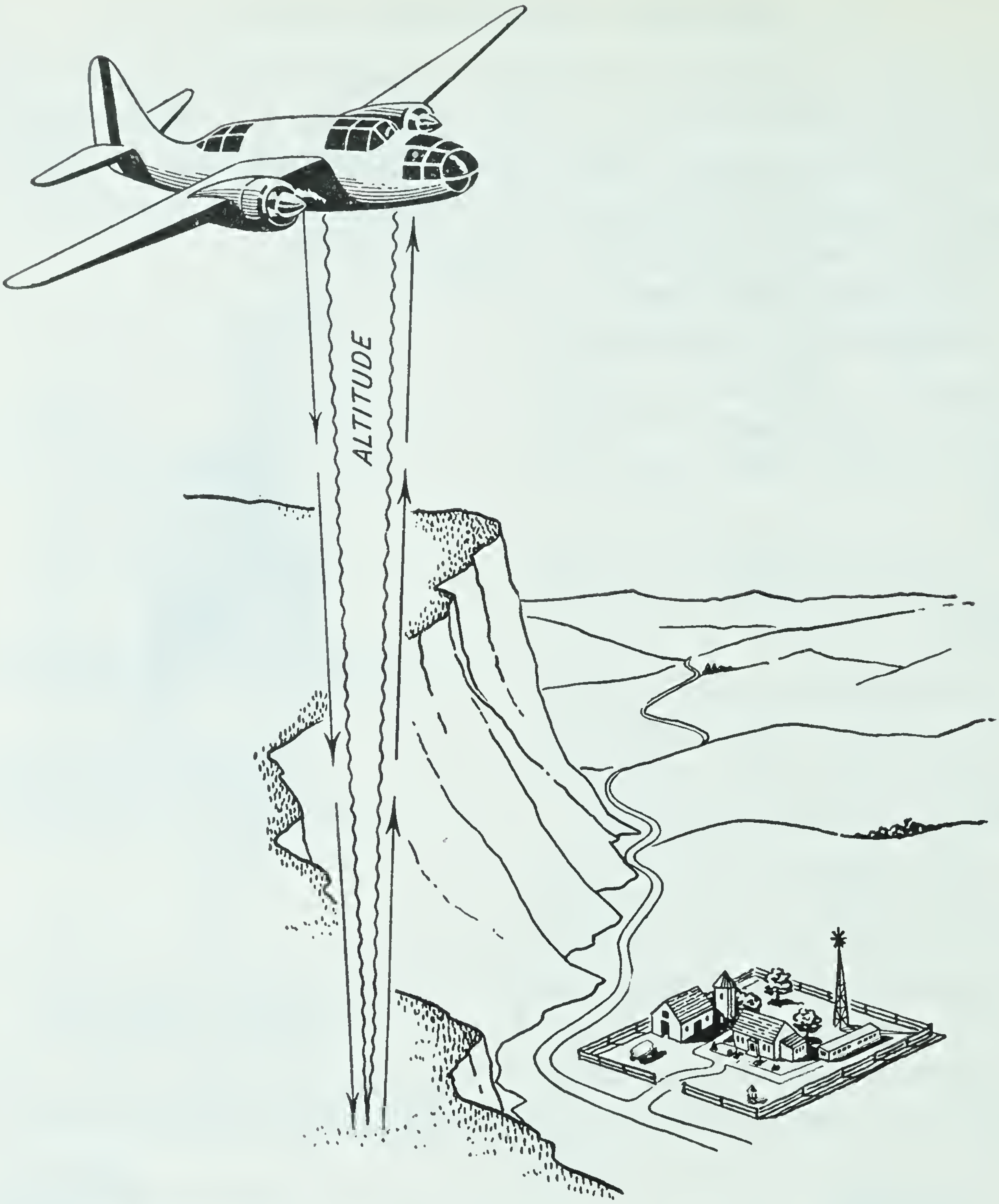


Fig. 209. The distance above ground may be determined by the time it takes a reflected radio wave to return to the airplane

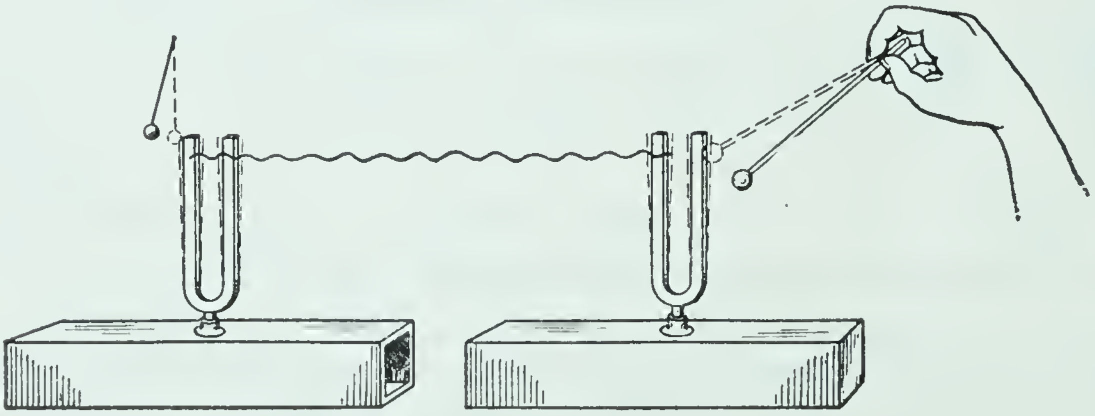


Fig. 210 *a*. Sympathetic vibrations

Reinforcement of sound by resonance. The intensification of sound by combining reflected and direct sound waves can be shown by use of a resonance tube. A vibrating tuning fork which cannot be heard at a short distance emits a sound that can be heard over the room when placed over a tube having an air column of the proper length.

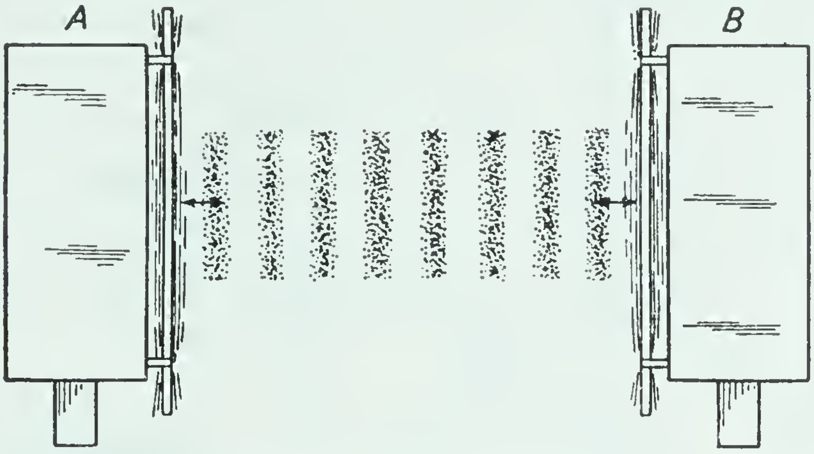


Fig. 210 *b*. Energy transmitted from bar *A* by sound waves sets bar *B* into vibration when the bars have the same vertical period of vibration

Fig. 211. A child's swing is an example of sympathetic vibration

The maximum sound results when the length of the tube is such that a condensation leaving the fork at *A* (see Fig. 214) will make the round trip to the water and return in time to reinforce the new condensation produced by the fork at *B*. During this time the fork must have made half a vibration, and the compression wave has traveled half a wave length. If half a wave length is the distance to the bottom of the tube and back, the length of the tube must be one-fourth of the wave length of the note. If the resonance tube is a foot long, the wave length is four feet. By dividing the speed of sound in feet per second by the wave length, the pitch of the note is determined. Resonance occurs at other tube lengths such as $\frac{3}{4}$, $\frac{5}{4}$, and $\frac{7}{4}$ of a wave length. While resonance is important in increasing or amplifying sound, probably its most important application is in the field of radio. Through resonance, stations can be selected and signals amplified. Without resonance radio would be impossible.

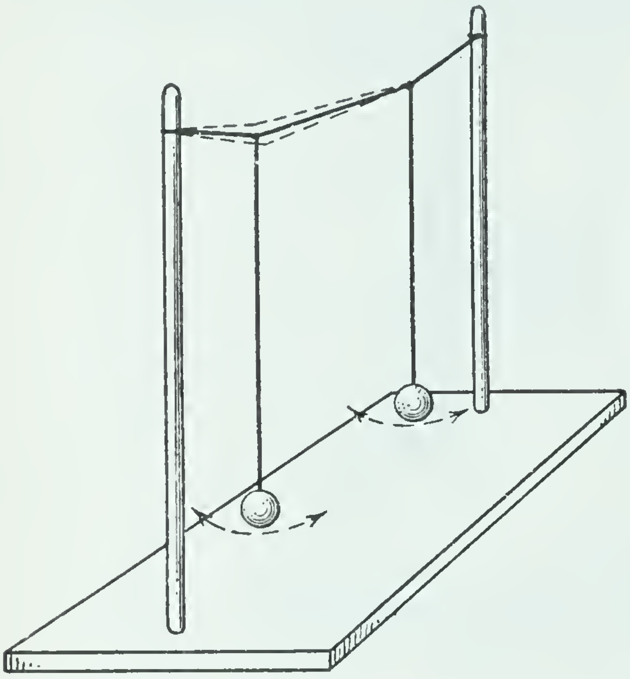


Fig. 212. Energy transmitted by the string sets the right-hand pendulum into sympathetic vibration.

Fig. 213. The car may vibrate strongly at one speed. Vibrations diminish at higher or lower speeds.

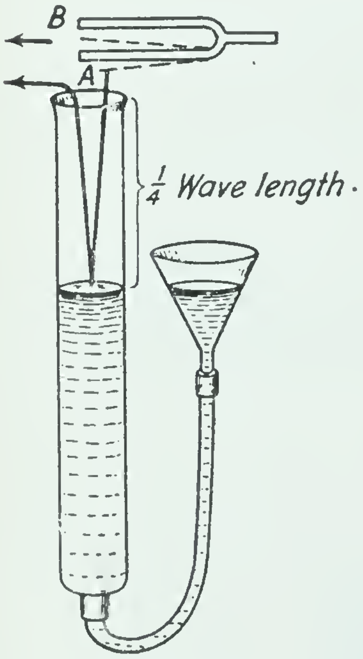


Fig. 214. The resonance tube

Interference of sound.

Laboratory Exercise 14. *Equipment:* Tuning fork, singing flame.

a. Walk about the room while a singing flame is in operation and describe any peculiarities of sound.

b. Rotate a sounding tuning fork close to the ear and explain the peculiarities (Fig. 215).

As a rule, one plus one makes two, but the exception to this rule is in sound. The addition or combination of two sounds may produce an increase in strength or intensity through the two sounds reinforcing each other (Fig. 216*a*). On the other hand, the two sounds may combine so as to neutralize each other and produce silence (Fig. 216*b*).

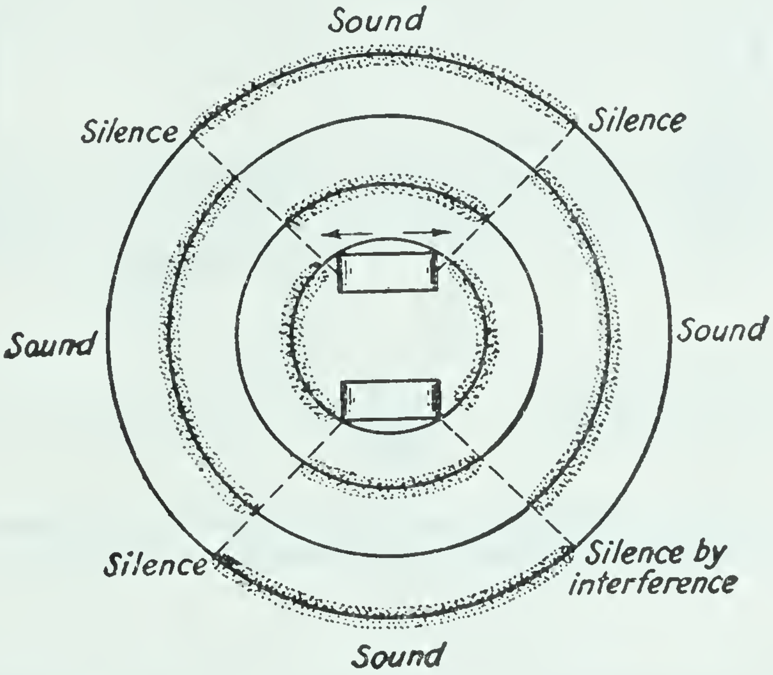


Fig. 215. Sound waves about a tuning fork

Standing waves are produced when two trains of waves of the same length and amplitude travel in opposite directions (Fig. 217). In an auditorium, direct and reflected waves combine to increase or decrease the sound intensity at different points, depending on whether the waves add or neutralize at the point under consideration. This action is more pronounced with music than with speech, since music more closely resembles the continuous waves we have considered, while speech consists of many frequencies.

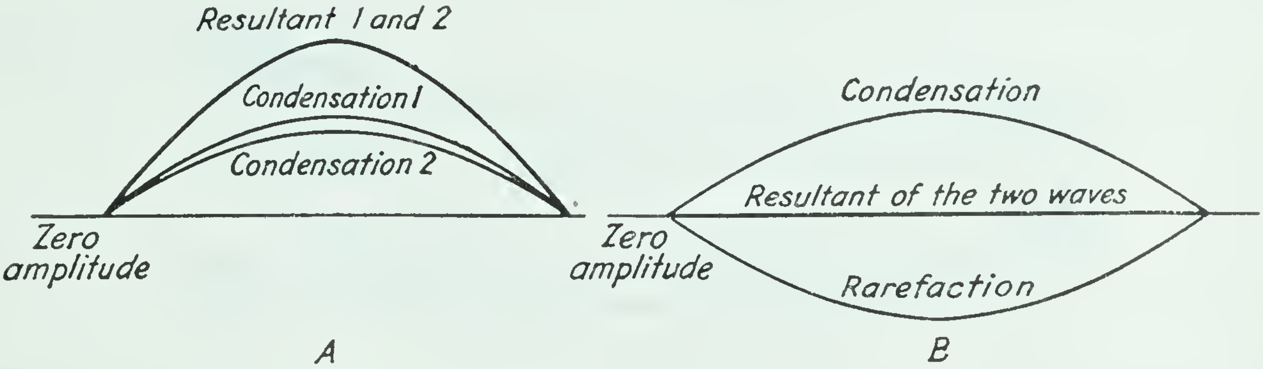


Fig. 216. Reinforcement and interference of sound waves

The acoustics of the room may be improved by use of sound-absorbing materials which tend to reduce the intensity of the reflected wave. Radio waves, like sound waves, can be reflected. The reception of some broadcasting stations may be poor at some distances because of waves reflected from the upper atmosphere. Other receivers at greater distances may enjoy good reception.

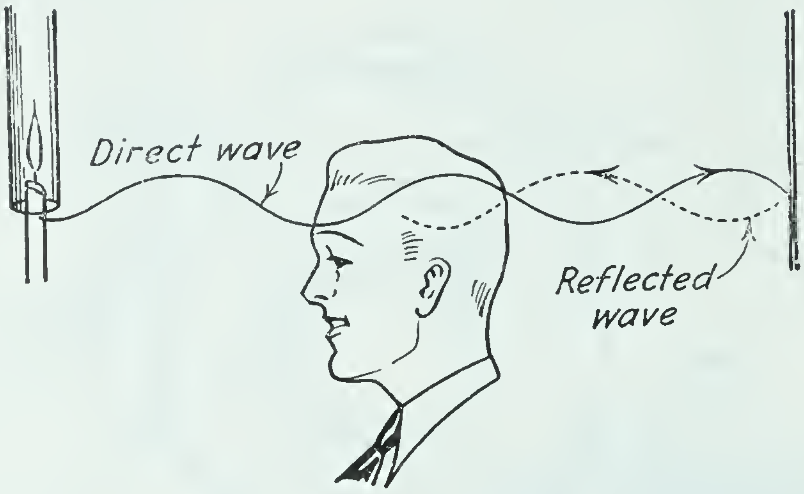


Fig. 217. Standing waves produced by reflection of sound waves

Beats.

Laboratory Exercise 15. *Equipment:* Two resonance boxes, two tuning forks, two singing flames.

a. Place two resonance boxes with tuning forks side by side and set the forks into vibration. Describe any variation in sound.

b. Load one fork slightly by the addition of a paper clip and note change in sound.

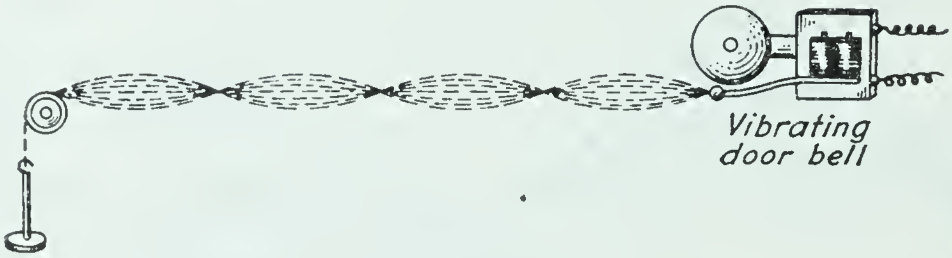


Fig. 218. Sound waves produced in a vibrating string

c. Place two singing flames close together while singing. What causes the throbbing sound when one tube is made a little longer than the other?

We have seen how two sounds of the same frequency may combine to produce an intense sound or silence. When waves of different frequencies combine, the intensity swells and falls with perfect regularity because of alternate periods of reinforcement and interference. This rhythmic phenomenon is referred to as beats, the number of beats per second indicating the difference of frequency of the two sound sources (Fig. 219).

Discord results from six or more beats per second. When a musical instrument is being tuned, the beats disappear as the string approaches the pitch of the standard with which it is being compared.

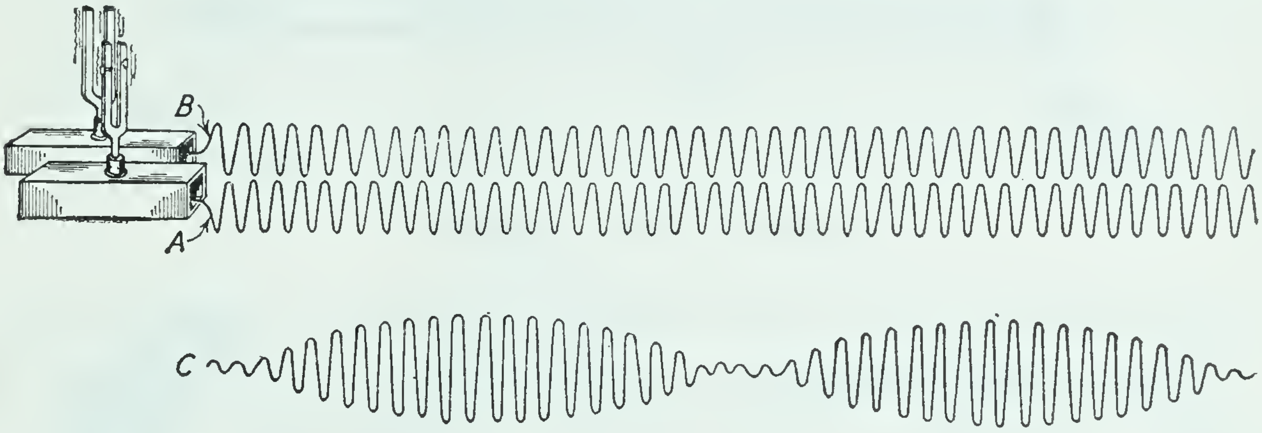


Fig. 219. Sound waves may be illustrated as transverse waves. Waves *A* and *B* combine to produce the pulsating beat note represented by *C*.

Radio waves like sound waves can produce beats. In a radio using the superheterodyne circuit, the pitch of the beat frequency is far above the hearing range. By selecting a beat frequency which can be amplified, the performance of the receiver is improved.

Quality of sound.

Laboratory Exercise 16. *Equipment:* Electric vibrator and string sonometer with movable screen.

a. Change the length and tension on the string attached to the electric vibrator (Fig. 220). Can a string vibrate in one or more sections?

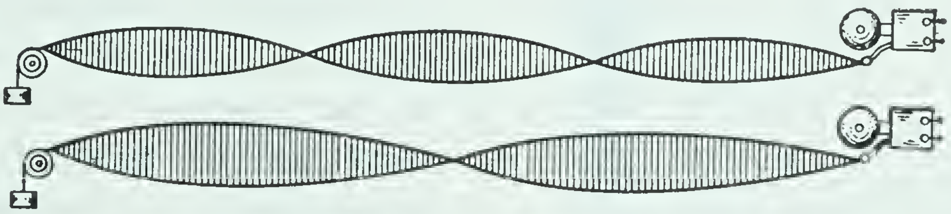


Fig. 220. A vibrating string

b. Hold the sonometer in front of a strong light or window and view the vibrating wire through the slot while shaking the screen. What difference of wave shape results from plucking the string at the center and near the end (Fig. 221)?

When a piano wire vibrates as a whole, it gives the lowest note which it is capable of giving. This note is called the fundamental. A wire plucked near one end vibrates not only as a whole but also in two, three, four, or more segments. These vibrating segments produce higher-pitched notes called overtones. Most musical instruments give several overtones in addition to the fundamental tone. The fundamental frequency of the speaking voice may range from 90 to 300 vibrations per second while the harmonics or overtones may go as high as 6000 vibrations per second. Because of differences in strength and number of overtones, we are able to distinguish between two voices singing the same fundamental note. The fundamental tone and all the overtones combine to make a complex sound wave as seen on the sonometer when the string is plucked near one end. It is interesting to note that resonators which respond to various pitches can be used to detect the various frequencies which together make up a complex sound wave. The diagram (Fig. 222) shows how a complex wave is built up through a combination of a fundamental tone and several overtones. Resonators designed to respond to the fundamental and to the respective overtones are also shown in the diagram. These resonators may be used in the analysis of the complex wave. Complex sound waves produced by the human voice may be readily observed by means of the manometric flame apparatus shown in Figure 223.

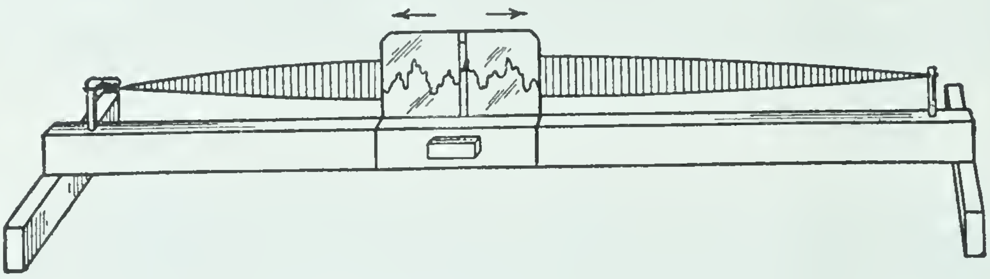


Fig. 221. A visual sonometer

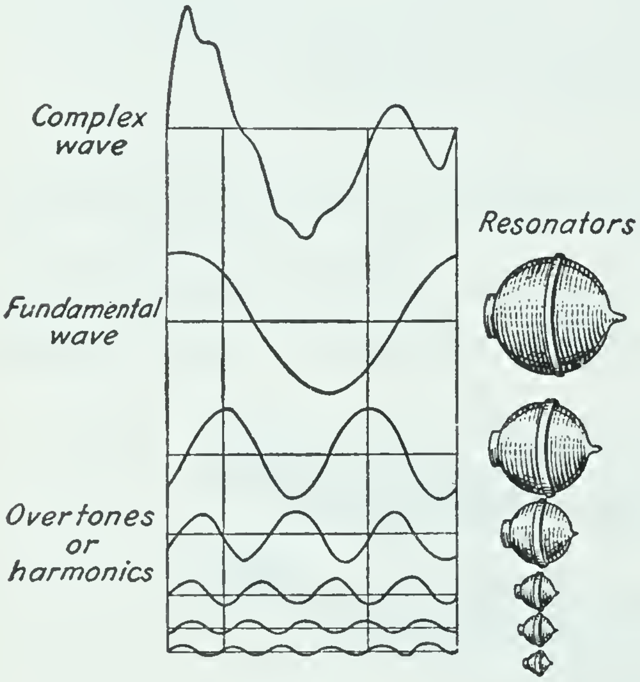


Fig. 222

Some special telephone lines may carry hundreds of voices in one complex electrical wave which is sorted or unscrambled by electrical resonators at the receiving end. Each resonator is connected to a telephone and delivers to it only one of the hundreds of voice messages going over the line at the same time.

Imagine the confusion which would result if 480 persons would try to talk to 480 other persons over the ordinary telephone line!

A radio receiver makes use of a resonance circuit to select the desired frequency and program from the complex radio waves set up by the various sending stations of the locality.

Exercise 17. In what way does a sound wave differ from a water wave?

Exercise 18. In what respects do sound waves differ from radio waves and light waves?

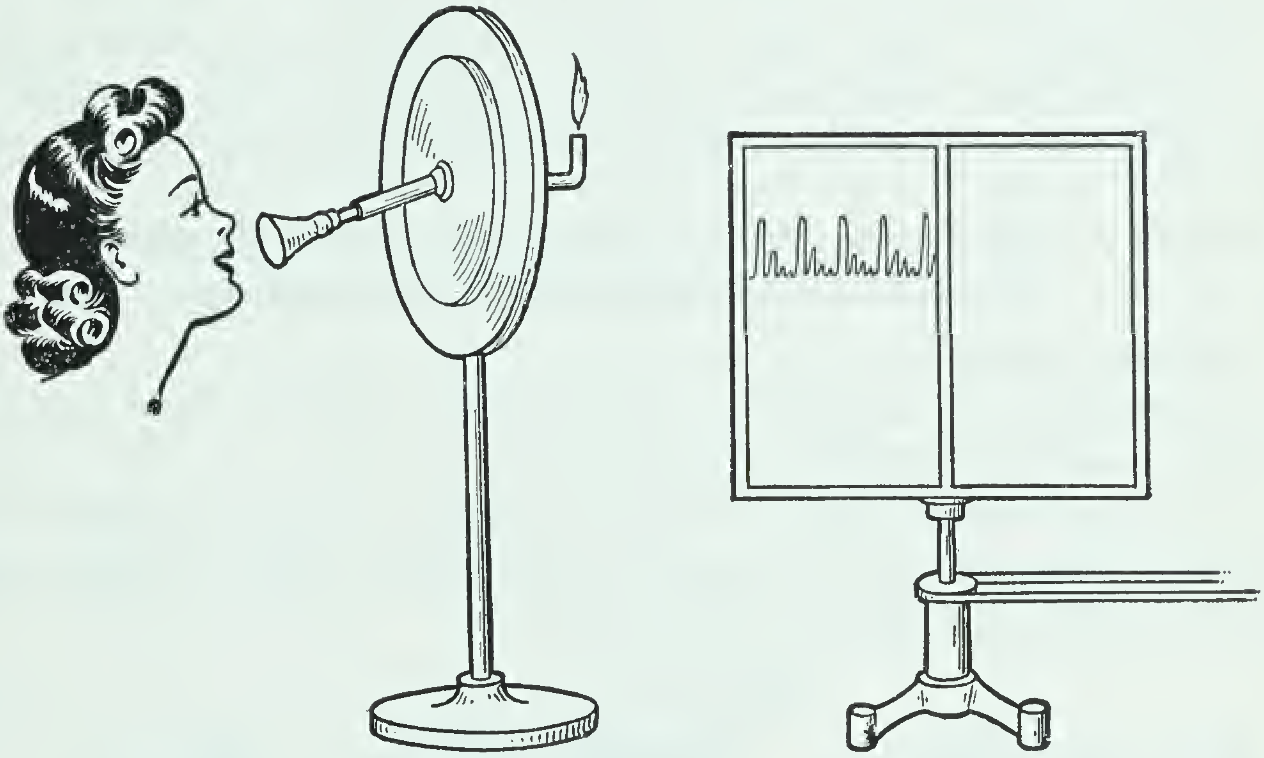


Fig. 223

Exercise 19. Explain how a sound travels from a tuning fork to the ear.

Exercise 20. If a flash of lightning is seen 15 seconds before the thunder is heard, approximately how many miles away was the flash?

Exercise 21. What two factors determine the pitch of the sound produced by holding the corner of a card against the different rows of holes in a rotating siren disk?

Exercise 22. If sound travels at a speed of 1130 feet per second, at 70° F., how long should it take for an echo to return from a wall 565 feet away at that temperature?

Exercise 23. Explain how radio waves can be used to determine the altitude of an airplane.

Exercise 24. Explain how reinforcement of sound is secured through use of a resonance tube.

Exercise 25. If a tuning fork making 256 vibrations per second is held over a resonance tube, what length of tube will produce resonance if the temperature is approximately 70° F.?

Exercise 26. Explain how one tuning fork can cause sympathetic vibrations in a second fork placed some distance away from the first.

Exercise 27. Explain how sounds from two forks of slightly different pitch are able to produce beats.

Exercise 28. How may a simple sound wave be illustrated by the visual sonometer? How may a complex wave be illustrated by the same device?

Exercise 29. How may a complex sound wave be analyzed?

Exercise 30. How may a radio receiver be used to measure the various frequencies of the complex radio wave entering the antenna?

Problem 3. What are the mechanical and electrical principles involved in radio transmission and reception?

Radio waves.

Laboratory Exercise 31. *Equipment:* Electric bell, electric motor, motor-type electric shaver.

a. Turn on the radio and set the dial so that no station is audible. Turn the volume control to full volume. Why is a vibrating electric bell heard through the radio?

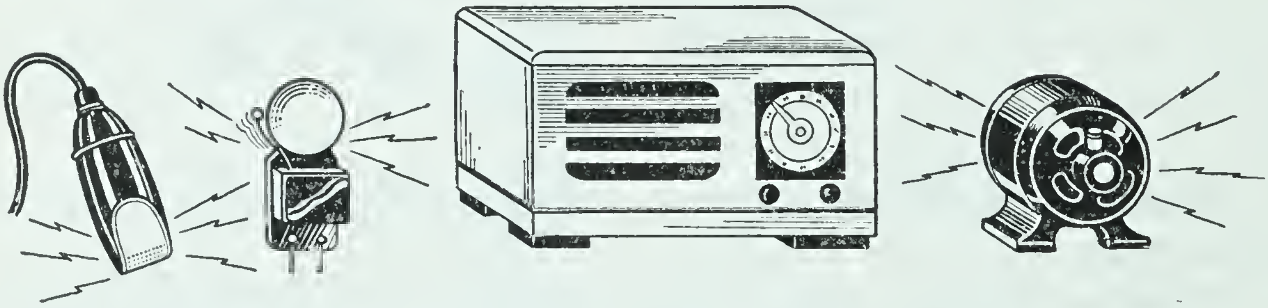


Fig. 224. Many electrical devices affect a receiver

b. What happens when a motor-type electric razor is brought near the radio and turned on?

c. What happens when a light switch is snapped on or off near the radio?

Almost everyone knows what broadcasting stations operate in his county or state, but many do not know that they may have several small broadcasting stations which operate occasionally in their homes. Many electrical devices, such as doorbells, motors, fluorescent lights, and light switches give off radio waves, which can be heard by means of a sensitive receiver. Other devices such as the ignition system on a car, X-ray machines, and power lines may give off stronger radio waves. Thanks to electric filters we do not always hear the disturbing sounds which ordinarily would come from these sources. Radio waves represent electrical energy that has escaped from electric circuits into free space. They travel at the speed of light (or 186,000 miles per second). "Believe it or not," a speech broadcast in an auditorium is heard by radio listeners several hundred miles away before the direct voice of the speaker is heard in the back of the auditorium.

While radio waves travel at the speed of light, they differ from light waves in frequency and in wave length. In radio as in sound, when the frequency is low the waves are long, and when the frequency is high the waves are short. The wave length of a radio wave in meters (1 meter = 39.37 inches) is found by dividing the velocity of the wave (30,000,000,000 meters per second) by the number of vibrations per second. There is a great variation in the range or distance that the waves of different radio frequencies will carry. The signal strength of long waves below 100 KC (100 kilocycles) as a rule does not vary much between day and night or from season to season. This band at times is used for long-distance transoceanic service. On the other hand, waves of broadcast frequencies show considerable variation. Stations using standard broadcast frequencies can be received from greater distances at night than in the day and from greater distances in winter than in summer. Waves of higher frequencies, 6000 to 30,000 KC, behave in a still different manner. Waves of this type reach distant points by refraction and reflection. The ionized layer of air in the upper atmosphere turns the waves earthward where they are again reflected upward. While this process may be repeated several times, the radio signal will be heard only at points where the wave returns to earth. The distance between these points is called the skip distance (Fig. 225).

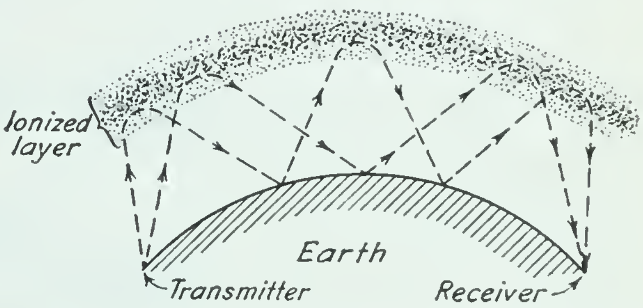
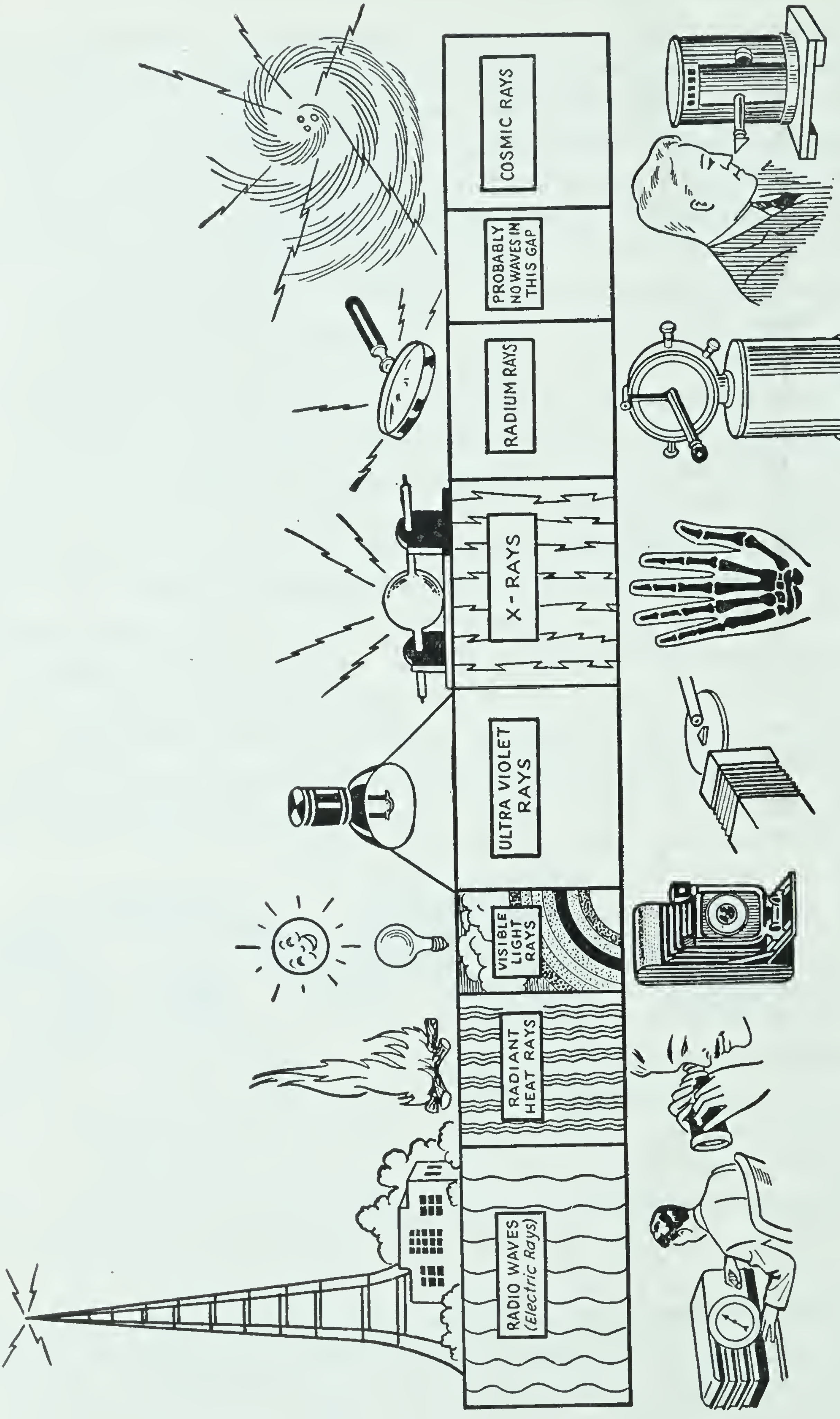


Fig. 225. The skip distance for short-wave radio

The electromagnetic spectrum. Beyond the frequency of radio waves are heat waves which are made known through the sense of feeling (Fig. 226). At still higher frequencies and corresponding to shorter wave lengths are light waves, made known by the sense of sight. This band of waves covers all the colors of the visible spectrum



Courtesy of Popular Science

Fig 226

ranging from red to violet. Beyond the violet is the ultraviolet with waves so short that it would take several hundred placed end to end to make a distance as great as the diameter of a hair. This invisible light, sometimes called "black light," is made known by its ability to cause certain substances to become fluorescent and thus to give light in the visible range. The commercial fluorescent light is an example of the use of this principle. Beyond the ultraviolet are still shorter penetrating waves called X-rays which are set up by a high-voltage electrical discharge in a vacuum tube. X-rays cause fluorescence of certain materials and also affect a photographic plate. Physicians and surgeons made use of the X-ray in diagnosis and in treatment of certain diseases. Next in the unbroken series of radiant waves are the so-called "gamma" rays of radium and radioactive substances which have properties similar to X-rays. Use is being made of these waves in treatment of malignant growths of cancer. Beyond the gamma rays of radium and separated from them by a gap in the long series of electromagnetic waves are the shortest known waves called cosmic rays. These waves of tremendous penetrating power come to earth from all directions in space. They may be considered as super X-rays capable of great penetration. No man-made device is capable of producing waves of this frequency. At the opposite end of the electromagnetic spectrum radio waves of desired frequency are produced at will by the control of oscillating electric circuits.

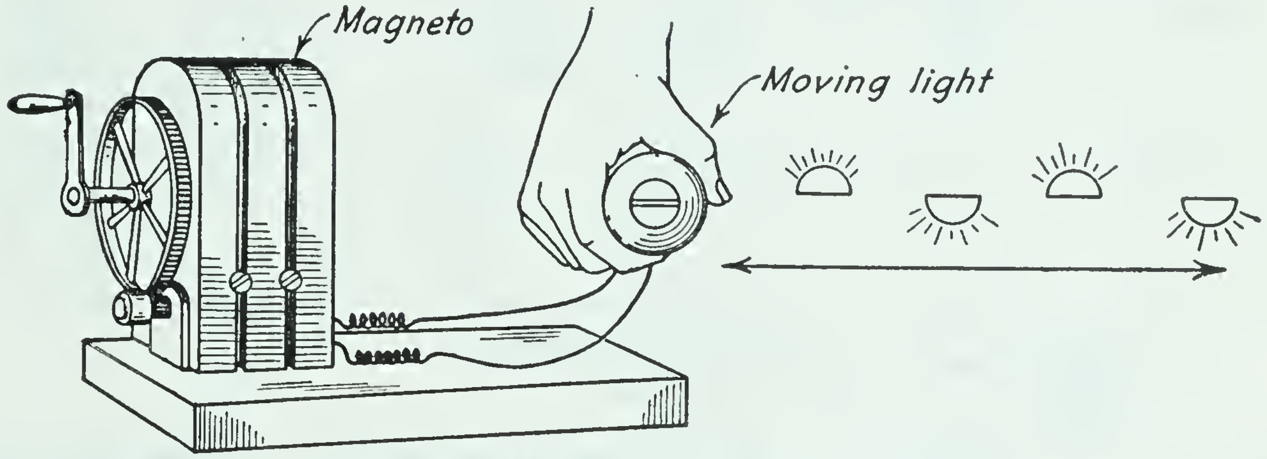


Fig. 227. Magneto and neon light

The production of alternating currents.

Laboratory Exercise 32. *Equipment:* Magneto, neon light.

a. Connect the magneto to the neon light and turn the crank. Describe the action of the neon light when stationary and when moving.

b. Connect the neon light to city current and move rapidly in the directions indicated. In what respect does the city current differ from the magneto current?

The magneto supplies an alternating current of low frequency. When the crank is turned rapidly, the frequency is higher, but not sufficiently high to stop the flicker of the light. For this reason an alternating current of higher frequency is supplied for the lighting circuit of the home. The 60-cycle current usually supplied to the home changes so rapidly that the eye does not detect the variations in light from most lamps. Because of the persistence of vision and because of the fact that a neon light responds almost instantly to current variations, these variations can be noticed in such a light if it is in motion.

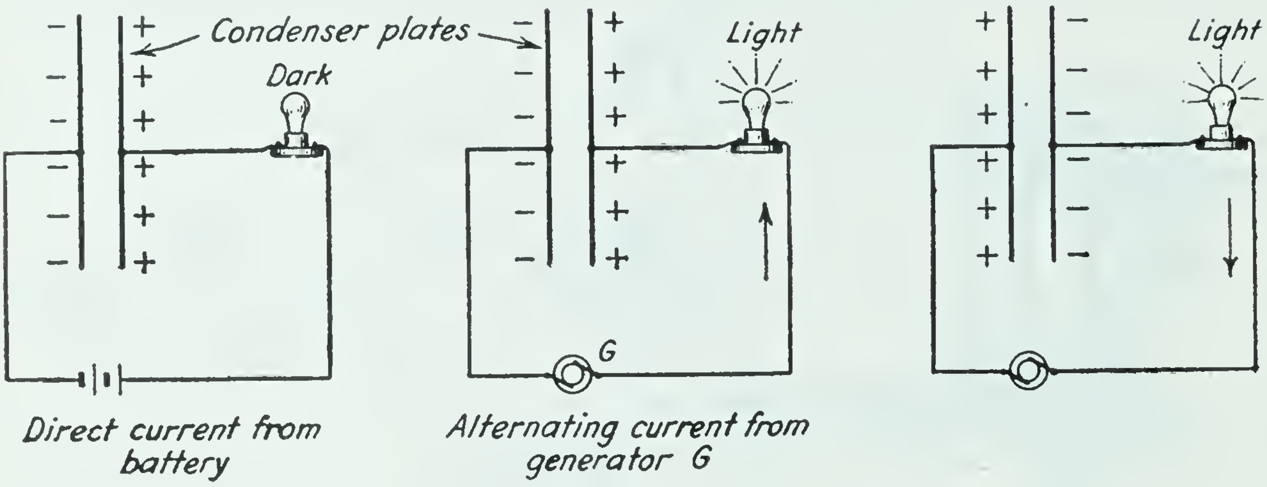

Condenser plates
Dark
Light
Light
G
Direct current from battery
Alternating current from generator G

Fig. 228. ***Left:*** **condenser in a direct-current circuit.** ***Middle*** **and** ***right:*** **condenser in an alternating-current circuit.**

Sometimes it is desirable to produce alternating currents of frequencies other than 60 cycles per second. The frequency of oscillation of certain circuits may be altered by changing the inductance or the capacitance of the circuit. The condenser consists of metal plates separated by some insulating material, such as air or paper. Positive and negative charges collect on these plates when they are connected to a battery. After the plates are charged, no more current flows because the circuit is not complete (Fig. 228). However, if a large paper condenser is connected to an alternating-current supply, a sufficient current will flow in and out of the condenser to light a small lamp (Fig. 228 *middle* and *right*).

Oscillators. When a neon light is placed in the circuit as shown in Figure 229, it will give intermittent flashes, the frequency of which depends upon the time required for the electric current to fill or "charge" the condenser. When the circuit is closed, a small current from the battery flows through the resistance *R* (Fig. 229) which gradually charges the condenser. When the voltage of the condenser builds up to a certain point, the neon tube becomes a conductor, and the condenser discharges through it until the voltage falls to the extinction point. The current again charges the condenser, and the process is repeated. The frequency of flashes may be varied by changing the battery voltage, the resistance of the circuit, or the dimensions of the condenser.

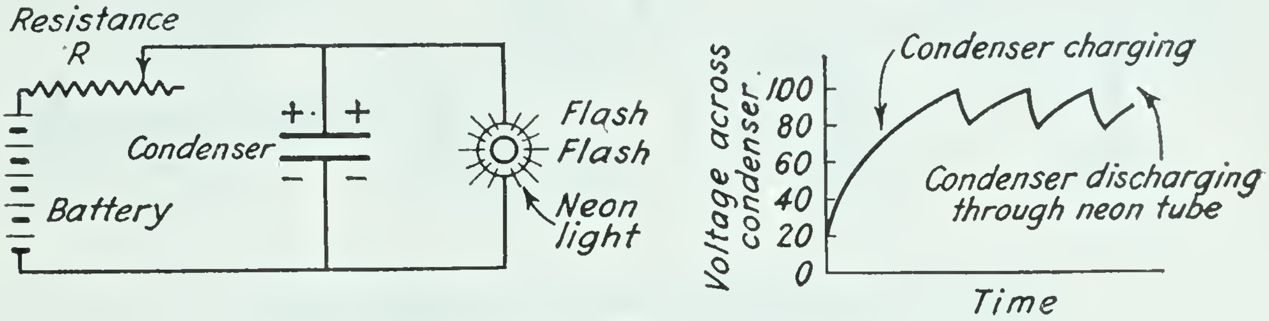


Fig. 229. The neon oscillator

Another type of oscillator sometimes used by boys in learning the wireless code is capable of producing frequencies as great as 1000 vibrations per second. A neon light connected with this oscillator must move very rapidly in order to spread the light enough to be seen as individual flashes (Fig. 230). By adding resistors or condensers to the circuit of this oscillator, notes of the musical scale may be produced and a miniature electric organ results in which push buttons take the place of keys. More elaborate devices, called audio-oscillators, have electric circuits which will produce oscillations covering the range of hearing. In these devices a loudspeaker is used to change the

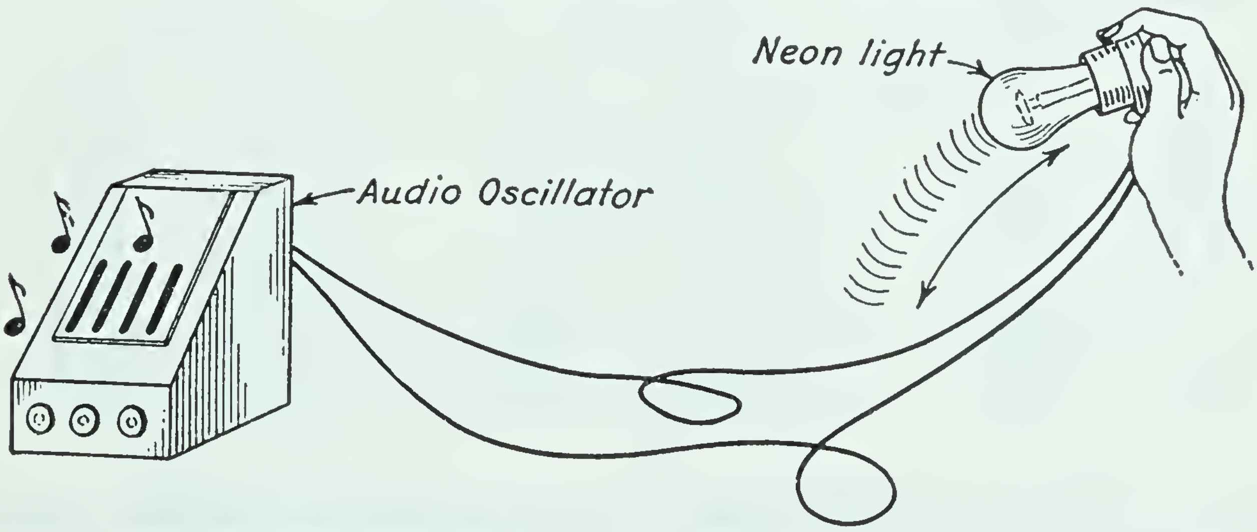


Fig. 230. The electric oscillation is heard through the speaker and seen in the flashing neon light

electric oscillations into sound waves. Other electric circuits are designed to oscillate many thousand or million times per second. These circuits are used in radio transmitters and receivers.

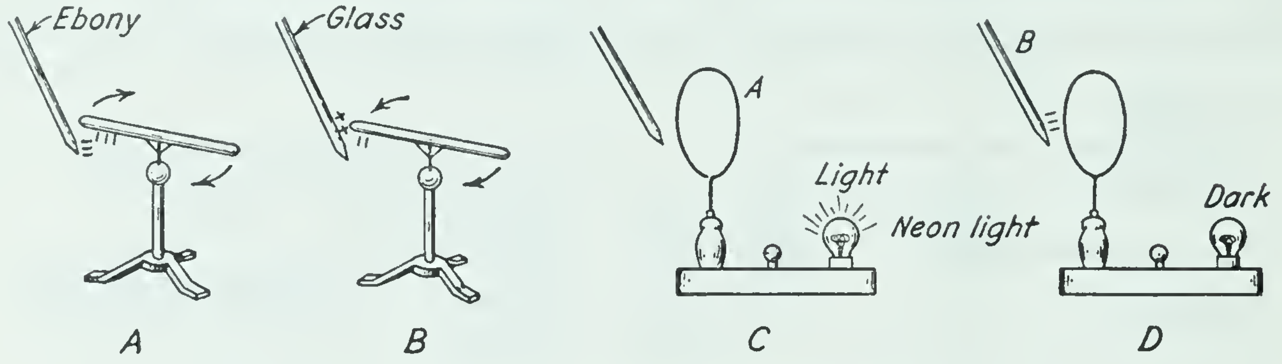


Fig. 231. Methods of detecting electric charges

The vacuum tube.

Laboratory Exercise 33. *Equipment:* Ebony rod, glass rod, fur, silk, insulated bar on stand, radio tube, static detector.

a. Rub an ebony rod on wool or fur to produce a charge. Touch it to the foil on the supported rod. Do like charges attract or repel? (Fig. 231*A*.)

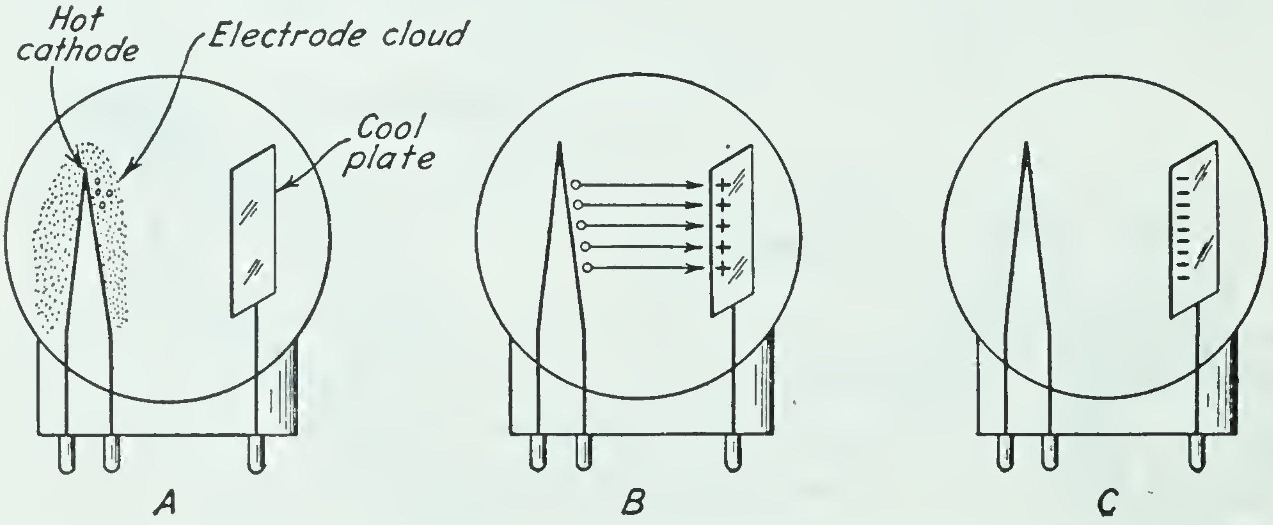


Fig. 232. *A*. Electrons are set free by heat. *B*. Electrons move to a positively charged plate. *C*. Electrons are not attracted to a negatively charged plate.

b. Rub the glass rod with silk to produce a positive charge. Do unlike charges attract or repel? (Fig. 231*B*.)

c. Move the charged rods near the loop connected to the grid of the radio tube. Which one is able to stop the flow of current through the neon light? (Figs. 231*C* and *D*.)

Perhaps no other development in the history of communications has contributed as much to modern radio as has the radio tube. Without it voice transmission and loudspeaker reception as we know them would be impossible. The simplest form of radio tube contains two elements, a cathode which is heated and a plate which remains cool. When the cathode is heated, electrons with a negative charge leave the surface and form an invisible cloud in the space around it (Fig. 232*A*). If a positive charge is placed on the plate, the electrons are attracted to it. Unlike charges attract. (Fig. 232*B*.)

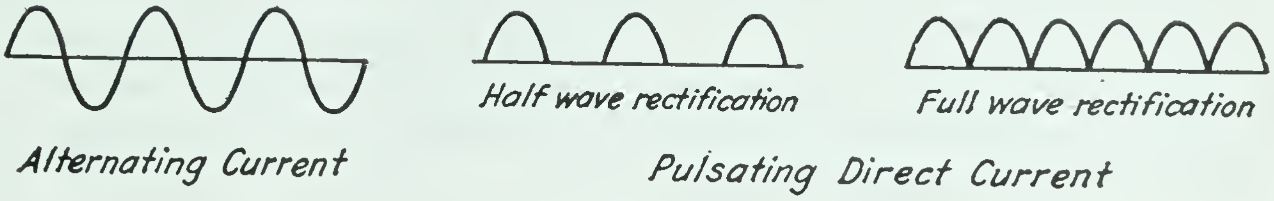


Fig. 233

This flow of electrons forms an electric current called the plate current. If the plate receives a negative charge, the electrons are repelled and no current flows (Fig. 232*C*). Since this type of tube permits current to flow only in one direction, it is used to change alternating currents to pulsating direct currents (Fig. 233). In Exercise 33 the rectifying action of the vacuum tube is shown by the fact that only half of the neon tube glows. When the tube is connected directly to an alternating current source, both halves of the tube glow.

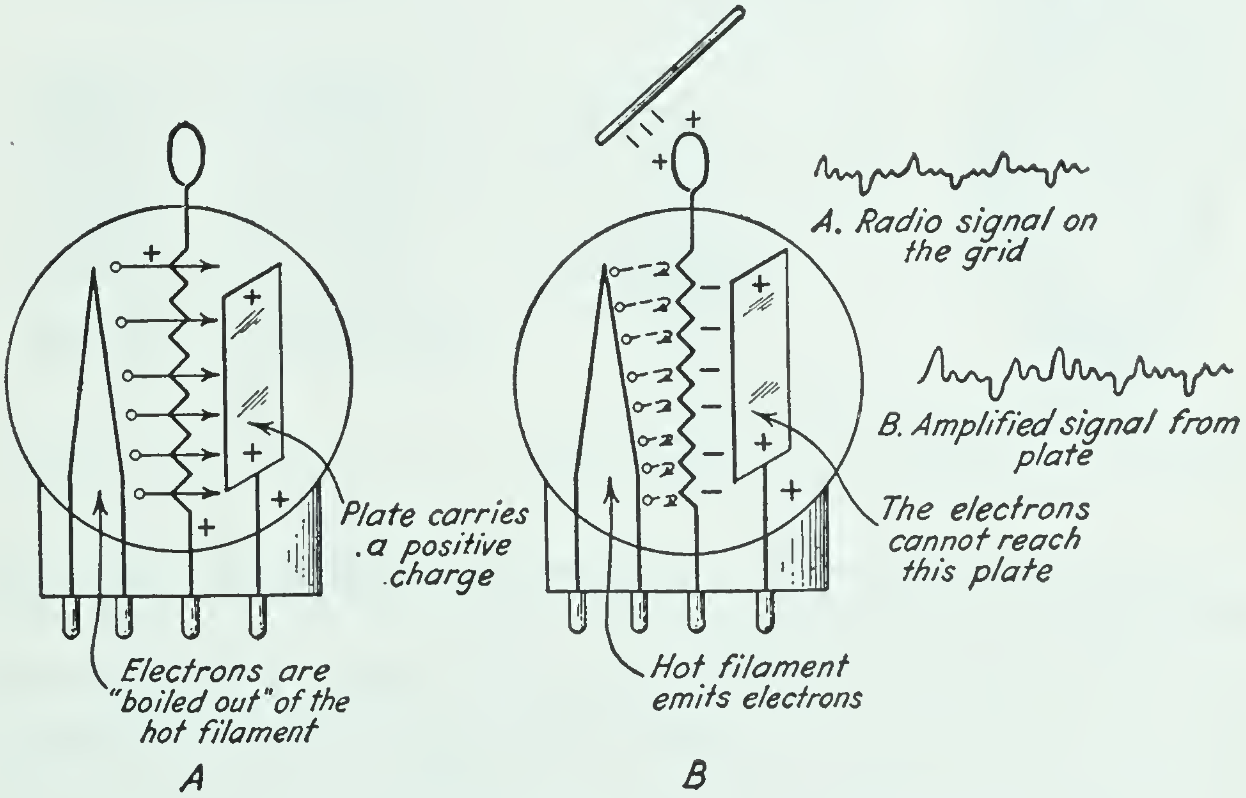


Plate carries a positive charge
Electrons are "boiled out" of the hot filament
A
A. Radio signal on the grid
B. Amplified signal from plate
The electrons cannot reach this plate
Hot filament emits electrons
B

Fig. 234. The grid action in a vacuum tube

The stream of electrons flowing between the cathode and the plate can be controlled by inserting a third element called the grid. A negative charge placed on the grid repels the electrons flowing towards the plate, thereby interrupting the plate current (Fig. 234).

The ability of a small grid charge to control the current through the radio tube and neon tube was shown in Figure 234*B*. Because of this valve-action principle, small variations in charge impressed on the grid of a radio tube by incoming radio waves are enlarged or amplified in the plate circuit.

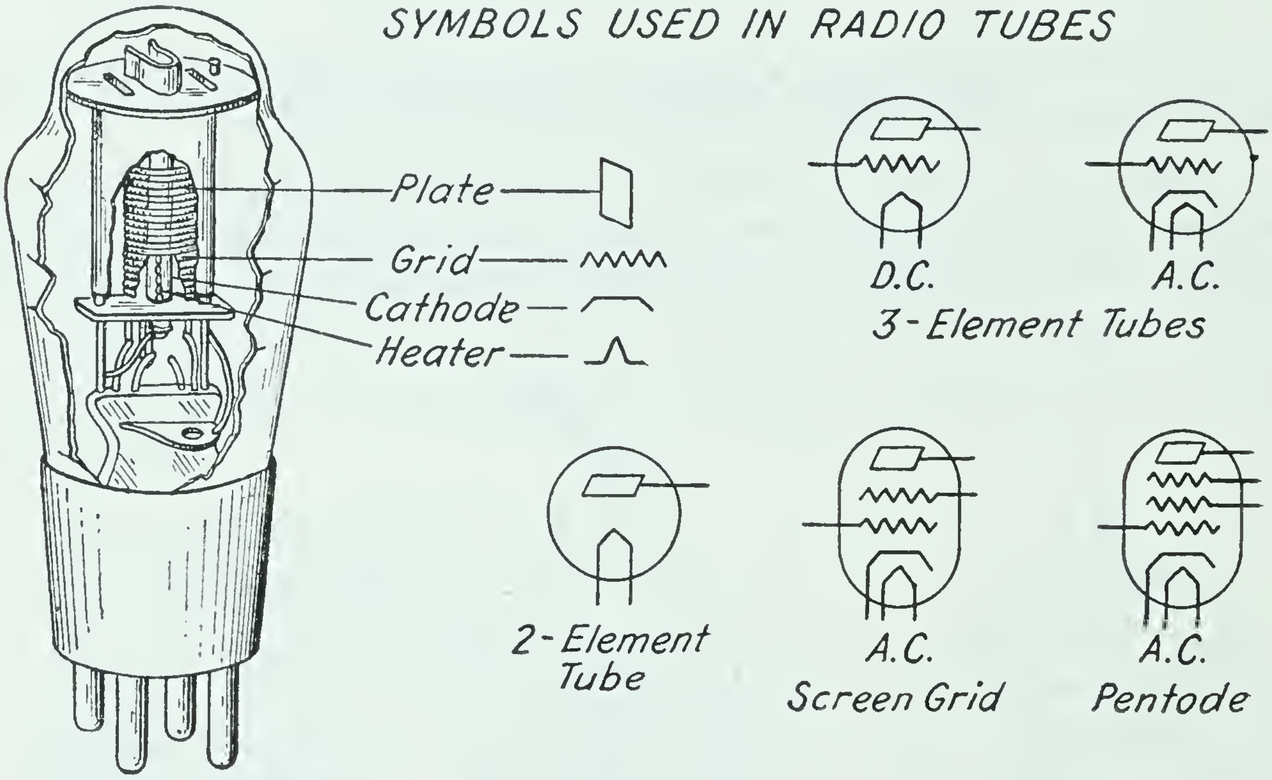


Fig. 235

Laboratory Exercise 34. *Equipment:* A discarded radio tube, end-cutting pliers or tin snips.

a. Break the glass of a discarded radio tube. With end-cutting pliers or tin snips cut each of the wires supporting the elements.

b. Remove the plate and observe the grid or grids of the tube.

c. Remove the grids and observe the cathode and heater.

The plate of a vacuum tube may be recognized as a metal sleeve surrounding the grid and cathode. The grid usually consists of a winding of wire around the cathode. This winding is spaced rather widely so that the passage of electrons between the cathode and plate is unobstructed by the turns of the grid. The cathode when heated yields the electrons for the plate current. The direct-heating type of cathode consists of a filament coated with an electron-emitting material. The indirect-heating type of cathode consists of a thin metal sleeve coated with electron-emitting material surrounding a heater element. This type of tube is well adapted for operation on alternating current. Modern tubes have additional grids in order to improve their performance and are sometimes sectioned in order to combine the functions of two tubes in one.

By use of several radio tubes, feeble radio signals from a distant radio station are amplified thousands or millions of times before they are strong enough to operate the loudspeaker of a receiver. In the broadcasting station the voice currents from the microphone are amplified millions of times before they reach the transmitting antenna.

How radio waves are produced. When alternating current of 60 cycles flows through a coil of wire, it sets up a magnetic field which reverses 60 times a second. If a second coil of wire, connected to an electric light, is placed in this field, the lamp glows, showing that energy is being transferred from one coil to the other (Fig. 236). The magnetic field extends a great distance beyond the coil. As the field reverses, some of the energy fails to return to the circuit. It escapes into free space as a radio wave which has a magnetic and electrostatic field capable of generating feeble electric currents in all conductors in its path. Over a short distance radio waves may set up voltages sufficient to produce sparks in an adjacent resonant circuit consisting of a condenser and a single turn or loop conductor (Fig. 237). The tower and the earth around a broadcasting station act as condenser plates. High-frequency alternating currents flowing in and out of this condenser circuit set up magnetic and electrostatic fields about the

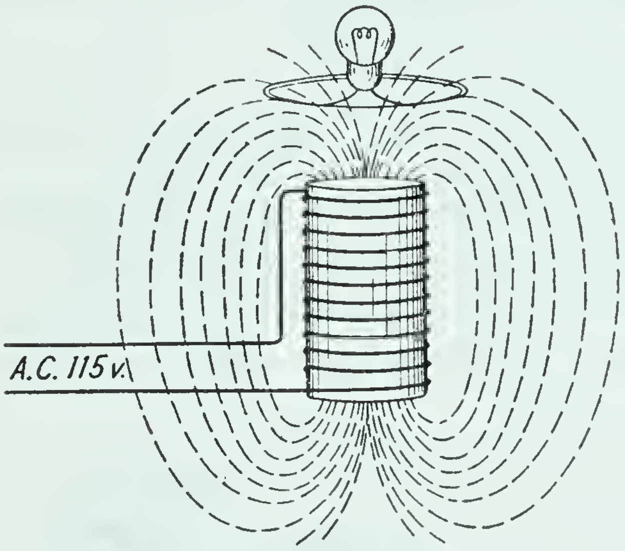


Fig. 236. Energy transfer without wires

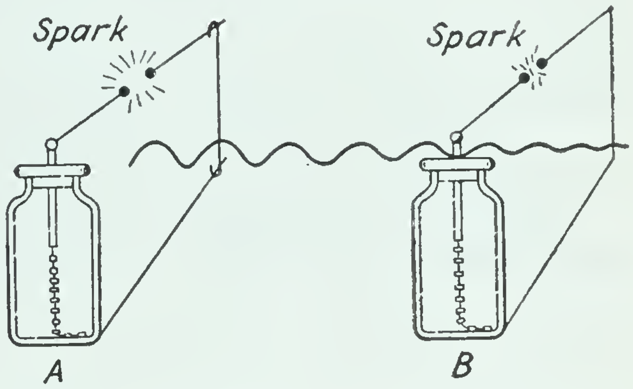


Fig. 237. Discharge of condenser in circuit *A* sets up radio waves which cause sympathetic oscillations in circuit *B*

tower. These currents supply the energy for the radio waves which escape and travel through space without wires.

Radio waves resulting from sparks in electrical devices such as motors, buzzers, switches, etc. are shown in Figure 238. Since these waves die out quickly, like the sound from a plucked string, they are called damped waves.

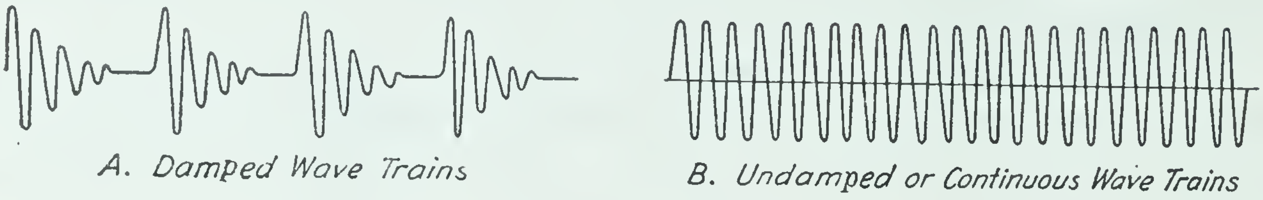


Fig. 238

With arrangements for strong sparks, code messages were sent by this type of wave in the early days of radio. On the other hand, voice and music could not be transmitted successfully by this intermittent wave. Continuous or undamped waves of the high frequency used in broadcasting were made possible by the invention of the vacuum-tube oscillator. The undamped radio waves may be likened to the sound waves of an organ pipe or steam whistle (Fig. 238*B*).

How the voice gets "on the air." When sound waves affect a microphone they cause corresponding voice currents. The fluctuating voice current can be made visible by placing a small flashlight in the microphone circuit. The flashlight now serves as a sort of visible broadcast antenna. Furthermore, the light waves from it are electromagnetic waves. The receiver of this broadcast must be a light-sensitive photo cell connected with a sound amplifier to reproduce the voice. By special equipment, voice has been carried more than 25 miles by light waves.

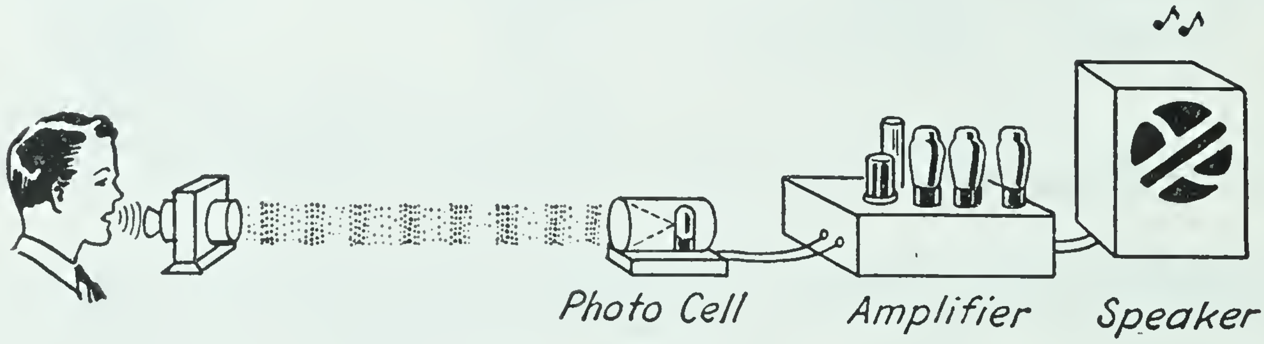


Fig. 239

Voice is carried by radio waves in much the same manner as it is carried over the fluctuating light beam. In radio broadcast, the voice currents from the microphone control or vary the strength of the station's radio wave or carrier wave. An oscillating electric circuit of the frequency assigned to the station produces the high-frequency alternating current which in a greatly amplified form affects and is radiated from the antenna as the carrier wave. The voice current from the microphone is also amplified to a strength sufficient to control or modulate the carrier wave (Fig. 240).

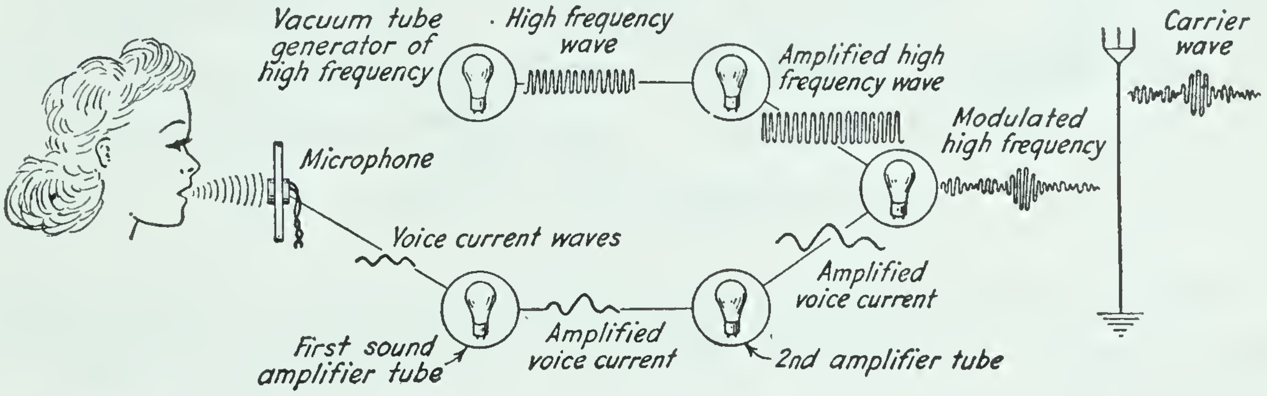


Fig. 240. Voice carried by light waves

Receiving radio signals. The musical pitch or frequency of a vibrating wire is determined by the tension, length, and size of the wire. The frequency of vibration may be altered by changing any one or more of these factors. The natural frequency at which an electric radio circuit will oscillate depends upon two factors: the coil or inductance and the size of the condenser or capacitance. By changing either or both of these factors, the circuit can be adjusted to respond to various frequencies. By turning the tuning dial of a radio the receiver circuit is adjusted to resonance with the frequency of the broadcasting station which it is desired to hear.

We have seen how sound waves arriving at proper intervals can set up sympathetic vibrations in a resonance bar placed at a distance (Fig. 210 *b*). In a similar manner radio waves arriving at the receiving antenna at proper intervals build up a strong electrical signal in the tuned receiver circuit (Fig. 241). However, this so-called strong signal is strong only by comparison to the signal strength of waves which are not in tune with the receiver circuit. Actually the aerial intercepts only an infinitesimal amount of energy sent out from a distant broadcast station, and, as a result, very feeble currents are induced in the aerial and in the receiver input circuit. Considerable amplification of these currents is necessary if the receiving set is to operate a loudspeaker. This is accomplished by use of vacuum tubes. The small voltage fluctuations of the signal are applied to the grid of a tube causing large current fluctuations of the plate circuit, thus reproducing the signal in amplified form. Several stages of amplification may be used to give the signal the desired strength. The voice frequencies are removed from the radio frequencies by the rectifying action of the detector tube. (See Fig. 241.)

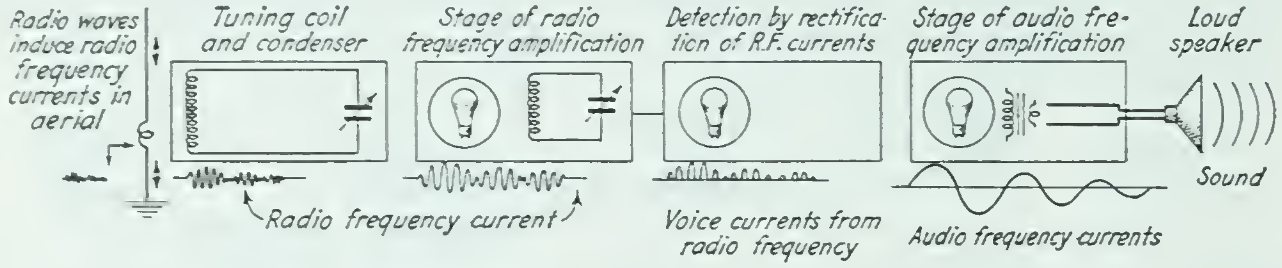

Radio waves induce radio frequency currents in aerial
Tuning coil and condenser
Stage of radio frequency amplification
Detection by rectification of R.F. currents
Stage of audio frequency amplification
Loud speaker
Sound
Radio frequency current
Voice currents from radio frequency
Audio frequency currents

Fig. 241. Radio-receiver circuit

One or more stages of audio amplification give the voice currents sufficient power to reproduce the voice at the receiving station over a loudspeaker.

There are several fundamental circuits used in radio receivers. The circuit arrangement known as the superheterodyne has proved to be the most efficient and adaptable type for aeronautical work. For this reason the circuit is discussed here. The following discussion of the superheterodyne circuit has been reproduced from the C. A. A. Manual 29 with only slight modification:

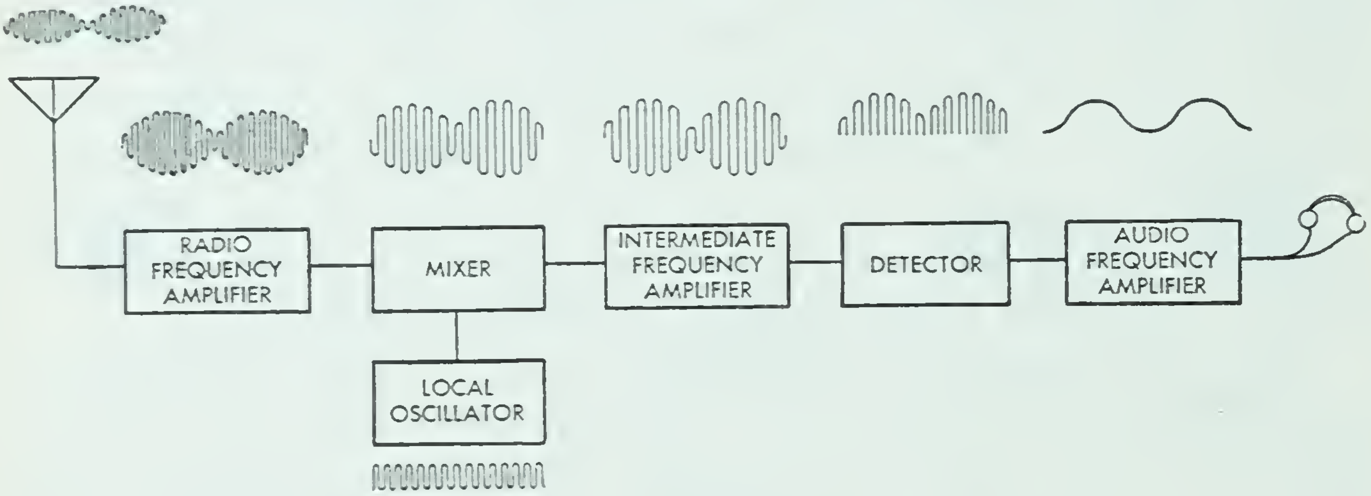

RADIO FREQUENCY AMPLIFIER
MIXER
INTERMEDIATE FREQUENCY AMPLIFIER
DETECTOR
AUDIO FREQUENCY AMPLIFIER
LOCAL OSCILLATOR

Fig. 242

"The action of this type of receiver can best be explained by means of the block diagram of Figure 242. The voice-modulated wave from the transmitter is intercepted by the antenna and amplified by the radio-frequency amplifier. This amplifier is composed of one or more vacuum tubes whose circuits are tuned to the radio frequency of the desired station. After amplification, the signal is passed on to the mixer tube. In this tube the incoming radio-frequency wave is superimposed upon another wave of different frequency which originated in the local oscillator tube circuit. A beat frequency or "intermediate" frequency is produced in this mixer tube in the same way as shown for sound waves in Figure 219. The intermediate-frequency circuit is designed to be insensitive to all but the intermediate- or beat-frequency and consequently accepts only that one. In many radio receivers, this intermediate frequency is about 485 kilocycles.

"In order to transform the incoming radio signal to the 485 kilocycles for passage through the intermediate-frequency stage, it is necessary to feed into the mixer tube from the local oscillator a frequency which differs from the incoming signal by 485 kilocycles. This is accomplished by simultaneously tuning the two circuits in such a manner that the locally generated signal always differs from the desired incoming signal by 485 kilocycles.

"Any amplifier which is designed to respond to one particular frequency is capable of operating much more efficiently than one which is forced to respond to a wide range of frequencies. Each element of the intermediate-amplifier circuit is expressly designed for only one frequency. This feature alone contributes much to the efficiency, selectivity, and other desirable characteristics of the superheterodyne receiver.

"After the signal passes through the intermediate-frequency amplifier, it is still vibrating at radio frequency. This is far above the limits of the human ear's response and must be reduced to an audio frequency. This is accomplished in the detector tube by rectifying or eliminating each half-cycle of the radio-frequency carrier and passing the rectified currents on to the audio amplifier in the form of pulsations. These pulsations vary in intensity as the original voice currents varied the output power of the transmitted signal.

"These audio-frequency pulsations are further amplified and the electromagnetic impulses converted to sound waves by the vibrating diaphragms of headphones or loudspeakers."

Since this type of receiver is extremely sensitive, it is essential that all electrical devices associated with the power plant of the airplane be adequately shielded in order to eliminate interference. In addition a low-resistance electrical path is provided between various parts of the plane in order to prevent the occurrence of minute sparks which are caused by the accumulation of static electricity on the plane.

Exercise 35. If radio waves are produced by many common electrical devices, why has their existence been known for only a few years?

Exercise 36. How long a time would be required for a radio wave to travel from a broadcasting station to a receiver 200 miles away? How long would it take the sound of the human voice to travel the same distance through air were that possible?

Exercise 37. What is the wave length in meters of a station broadcasting on a frequency of 600 kilocycles per second (1 kilocycle = 1000 cycles)? How long is this wave length if it is expressed in feet? In city blocks?

Exercise 38. Determine the wave length of a local station from the frequency given by the instructor.

Exercise 39. Explain how a radio tube amplifies or enlarges the signal placed on the grid of the tube.

Exercise 40. What is meant by a modulated-carrier wave?

Exercise 41. How does a detector tube recover voice frequency from radio-frequency currents in a radio receiver?

Exercise 42. Explain how a station is "tuned in" on a radio receiver.

Exercise 43. Explain how the intermediate frequency is produced in the superheterodyne radio receiver.

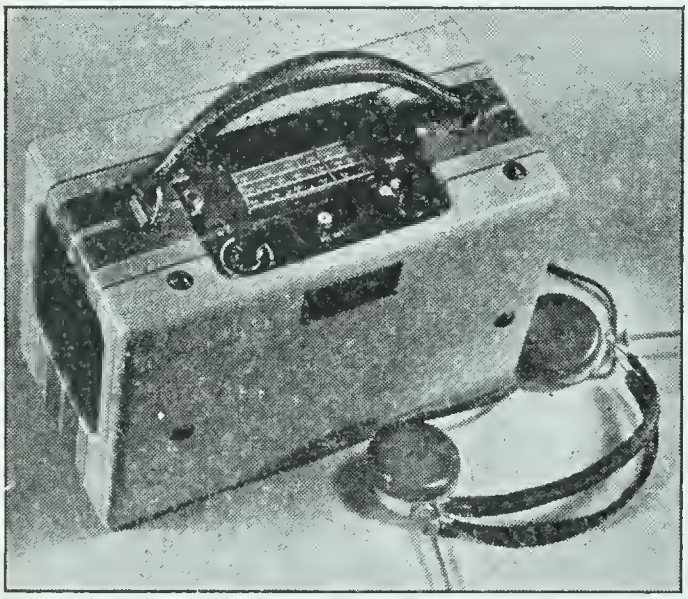


Fig. 243. Portable radio receiver for reception of flight information

Problem 4. What applications of communications systems are important in aviation?

The radio range. The development of dependable, efficient, inexpensive radios has resulted in widespread public use of radio receivers for entertainment. In addition, the demand for radio receivers in airplanes has steadily increased, not only because of improved lightweight equipment and an increasing number of aids, but also because radio continues to function during bad weather when the usefulness of other aids to air navigation often becomes negligible. Even the owner of a lightweight plane may enjoy radio range navigation with no more equipment than an inexpensive portable receiver (Fig. 243). With this equipment he may not only add to his safety (by receiving the latest weather reports while in flight) but also receive landing instructions from the control tower when he reaches the end of his journey. Already there are a number of airports where aircraft not equipped with radio are denied landing privileges except in case of emergency. War-time emergency has, of course, suspended some of these services.

The pilot receives much valuable assistance from the radio range and broadcast stations. Range stations located throughout the country are shown in Figure 244. In addition to the broadcast of various kinds of information, the radio range station transmits four courses or equi-signal zones, which are normally 90° apart, although this spacing is often varied in order that the courses may coincide with the established airways.

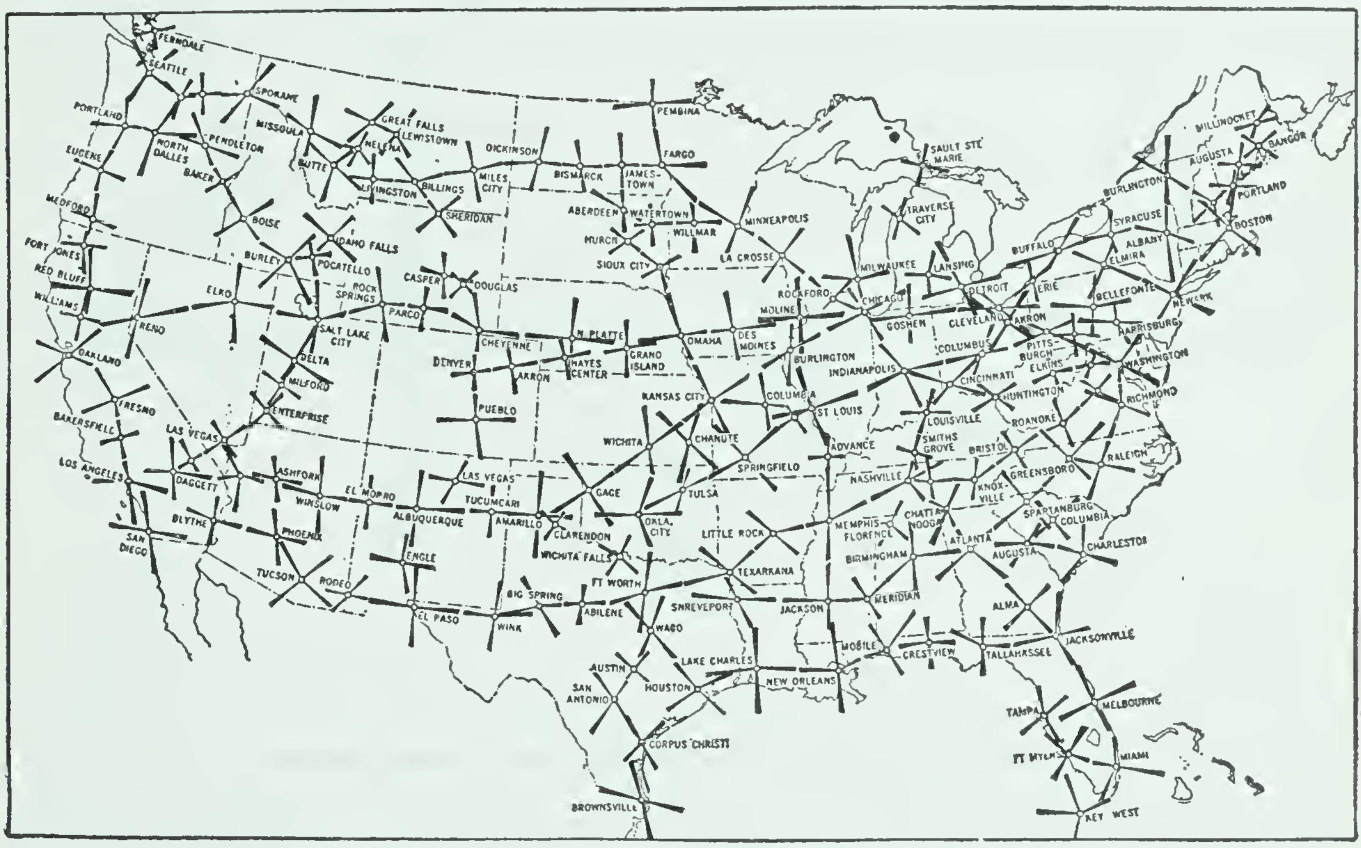


Fig. 244. The radio range system of the Civil Aeronautics Administration

The operation of some ranges is dependent upon the electromagnetic field that exists around closed loops of wire when excited by an electric current. If a battery is connected to a loop of wire (Fig. 245), a magnetic field in the shape of a figure "8" is produced. In the case illustrated, the shape of the magnetic field can actually be traced out by a simple magnetic compass.

If an alternating current at radio frequency instead of direct current from the battery is applied to the loop of wire, a signal will be heard on a radio receiver located at any point within the field pattern. Some radio range stations make use of two loops of wire placed at right angles as shown in Figure 246. A radio transmitter is connected first to one loop and then the other by an automatic motor-driven switch. A device designed to aid in visualizing the manner in which the fields of the two loops alternate is shown in Figure 247. Radiation from red light bulbs is used to represent the field of loop *A*.

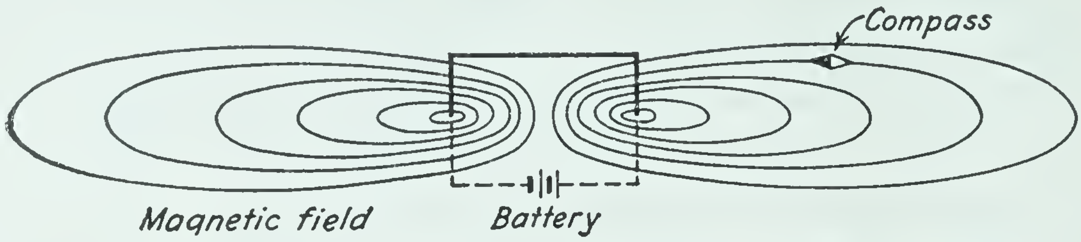


Fig. 245. The magnetic field about a loop excited with direct current

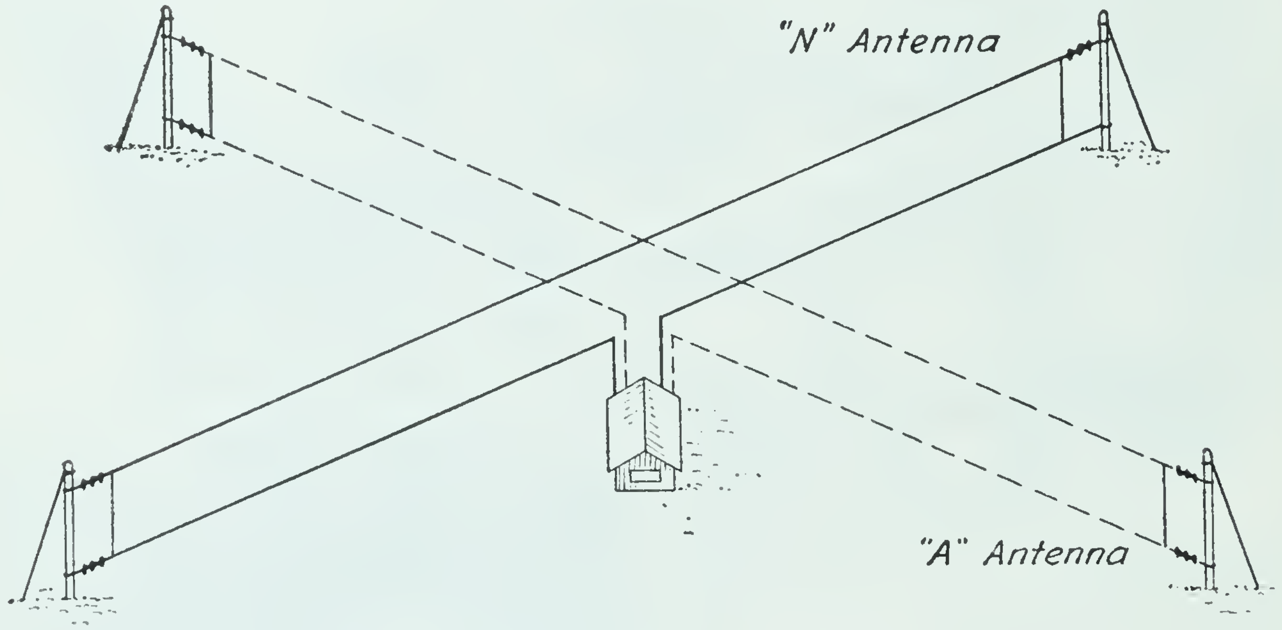


Fig. 246. Diagram of a loop-antenna range station

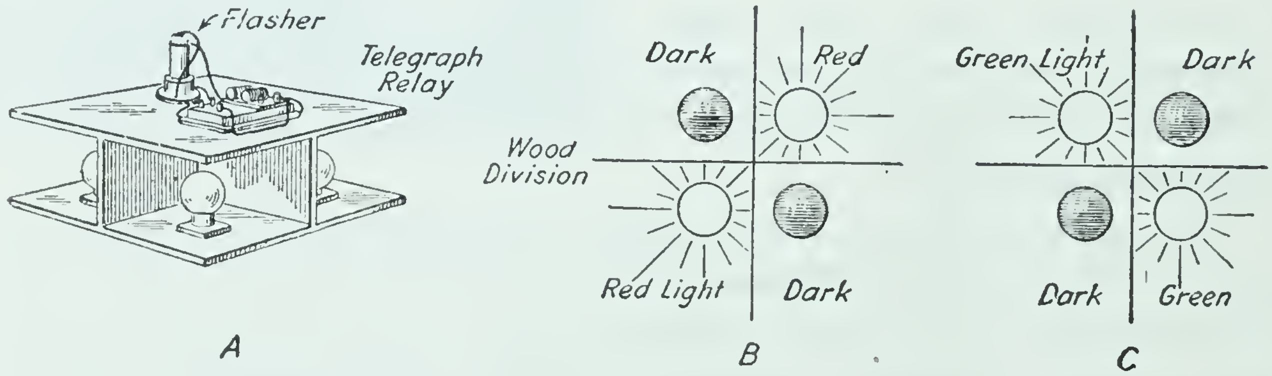


Fig. 247

In turn, a pair of green lights represent the second field or *N* loop. A relay and a telegraph key are used to switch the current from one pair of lamps to the other, thereby showing by light the manner in which the loops alternately radiate energy in diagonally opposite quarters or quadrants with considerable overlapping.

Laboratory Exercise 44. Construct a diagram showing the locations around the visual range model wherein one might expect to receive illumination of equal intensity from both a red and a green light.

The fields of the two loops of a radio range station are shown in Figure 248. (Other stations use 5 steel towers as radiators.) Four "on course" or equi-signal zones are also shown which are used to mark the airways between range stations. In these zones the dot-dash signal note of loop *A* combines with the dash-dot signal note of loop *N* to make a continuous note or monotone on each of the four "on course" zones. An airplane flying within an *N* field or quadrant will receive a constant repetition of the *N* signal (dash-dot). If the plane is within an *A*-signal quadrant, the *A* signal (dot-dash) will be heard continuously. In each case the strength of the background, or other quadrant signal, will be dependent on the distance the plane is off course. It follows that if a plane enters the shaded area, the signals *N* and *A* will be received with equal strength, resulting in a continuous note or monotone.

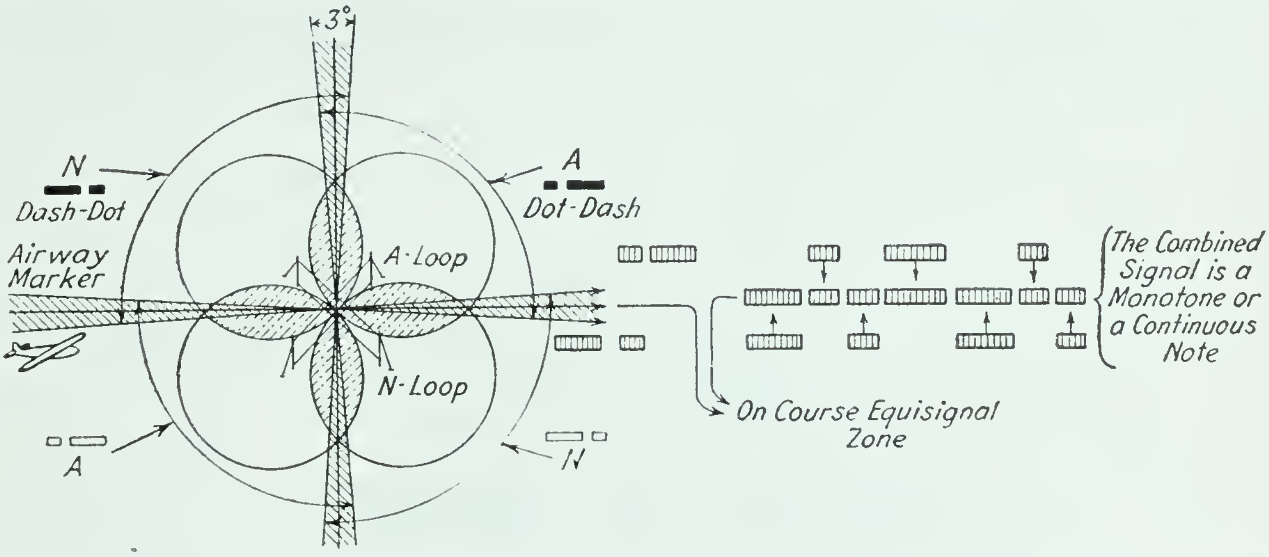

3°
N
Dash-Dot
A
Dot-Dash
Airway Marker
A-Loop
N-Loop
A
N
The Combined Signal is a Monotone or a Continuous Note
On Course Equisignal Zone

Fig. 248

Since the human ear is not a highly efficient sound-measuring device, small changes of signal intensity are not detectable. For this reason, there is an appreciable area on each side of the theoretical equal signal line which gives the illusion of width to the "on course" signal. The width of this sector depends upon the discriminating sensitivity of the individual ear and has been found in practice to average about 3° (Fig. 248).

In flying the course the pilot must keep to the right edge of the "on course" signal in much the same manner as automobiles in two-way traffic keep to the right of the center of the street. This procedure reduces the possibility of collision with other aircraft. However, as the pilot approaches the range station, he may fly "on course" in order to determine when he passes over the station. This is indicated by the "cone of silence" and by a reversal of quadrant signals.

The "cone of silence" is an inverted cone-shaped area above a range station. In this area the radio waves interfere or cancel, and no signal is produced (Fig. 249). As an airplane approaches a range station, the signal strength increases rapidly until the cone of silence is reached; then as the airplane enters the cone of silence the signals suddenly disappear or fade out. When the signal zone on the other side of the cone is reached, a strong signal of the new quadrant suddenly becomes audible. This signal diminishes in strength, rapidly at first, and then slowly, as the airplane increases its distance from

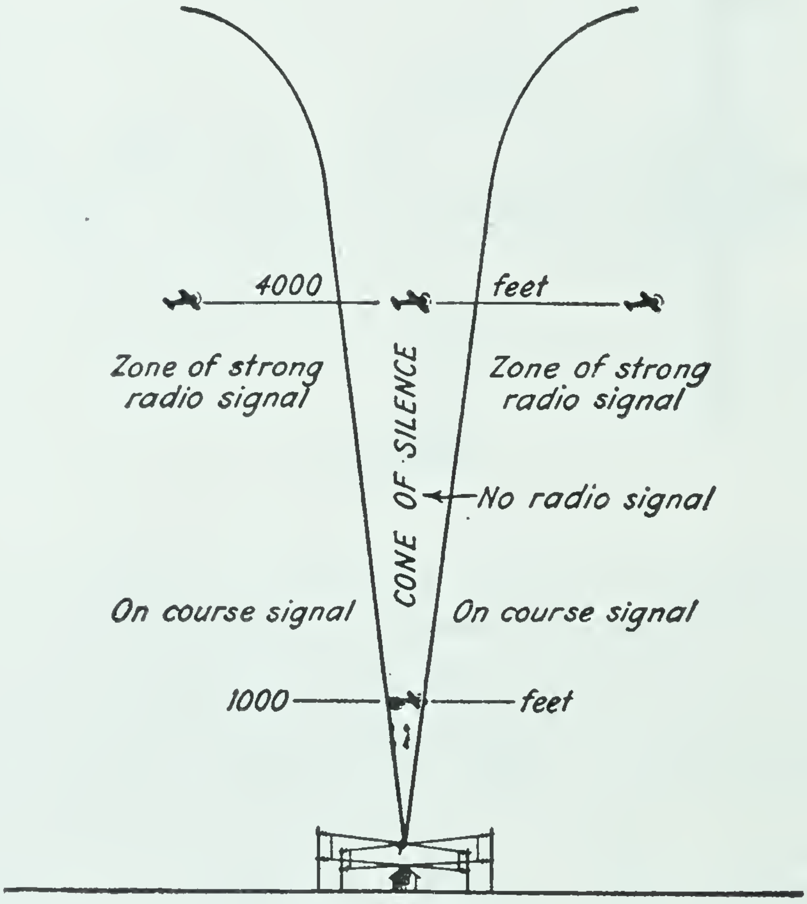


Fig. 249. The cone of silence

the station. If an airplane passes over a station slightly to one side of the cone, and if at the same time the receiver is not adjusted to a minimum volume, the signals do not entirely fade out and thereby warn the pilot that he is entering a new quadrant. In order to avoid uncertainty from this cause, most ranges are equipped with a station location marker which gives a distinct signal within the cone of silence. However, a pilot should know when he is going from one quadrant to another as he passes through an "on-course" signal.

The loop type of range, which was the earliest type used, was entirely satisfactory for daylight flying. However, the courses of the loop range often swing or alter their direction at night, sometimes to the extent that they are not usable at distances in excess of 30 miles from the station. Since the loop type of station is relatively inexpensive, a large number of them are operated where effective distances need not exceed 30 miles. The night effect or swing of "the course" at about 30 miles from the station is caused by waves which have traveled skyward from the top of the loop antenna. These waves are turned earthward by the upper atmosphere and strike the earth at a distance about 30 miles from the station, where they interfere with the direct signal of the range. This interference with the direct signal results in a shift of course or "night effect." There is still another disadvantage of the loop station. This type of station is not made to transmit both range and weather broadcast reports at the same time. In order to transmit a weather report, it is necessary temporarily to discontinue the range signal. When the weather report is broadcast for the benefit of one group of aircraft, another group may be flying "on instruments" and depending upon the uninterrupted range signal for accurate navigation.

To overcome this difficulty and also the "night effect," the simultaneous range has been developed, which makes possible the transmitting of range signals and radio-telephone messages at the same time and on the same frequency. This system employs four vertical towers at the corners of a square. Each pair of diagonally opposite towers is capable of producing the same figure-eight pattern of radiation that is produced by one loop of a loop range station. The additional fifth tower in the center not only carries the voice broadcast, but, by radiating a frequency slightly different from that of the corner towers, it produces a beat note for the range signal (Fig. 250). As a result, voice and range signals are heard simultaneously by the pilot. By intensive concentration it is possible for a pilot to receive either the voice or the radio range signal. However, such concentration on the signal would require the undivided attention of the pilot, who has many other duties to perform. This difficulty is overcome by providing electrical circuits to separate or filter the range signal of 1020 cycles from the voice broadcast. By use of this device the pilot has only to flip a switch in order to listen to the range signal, the voice broadcast, or the combination of voice and range signals.

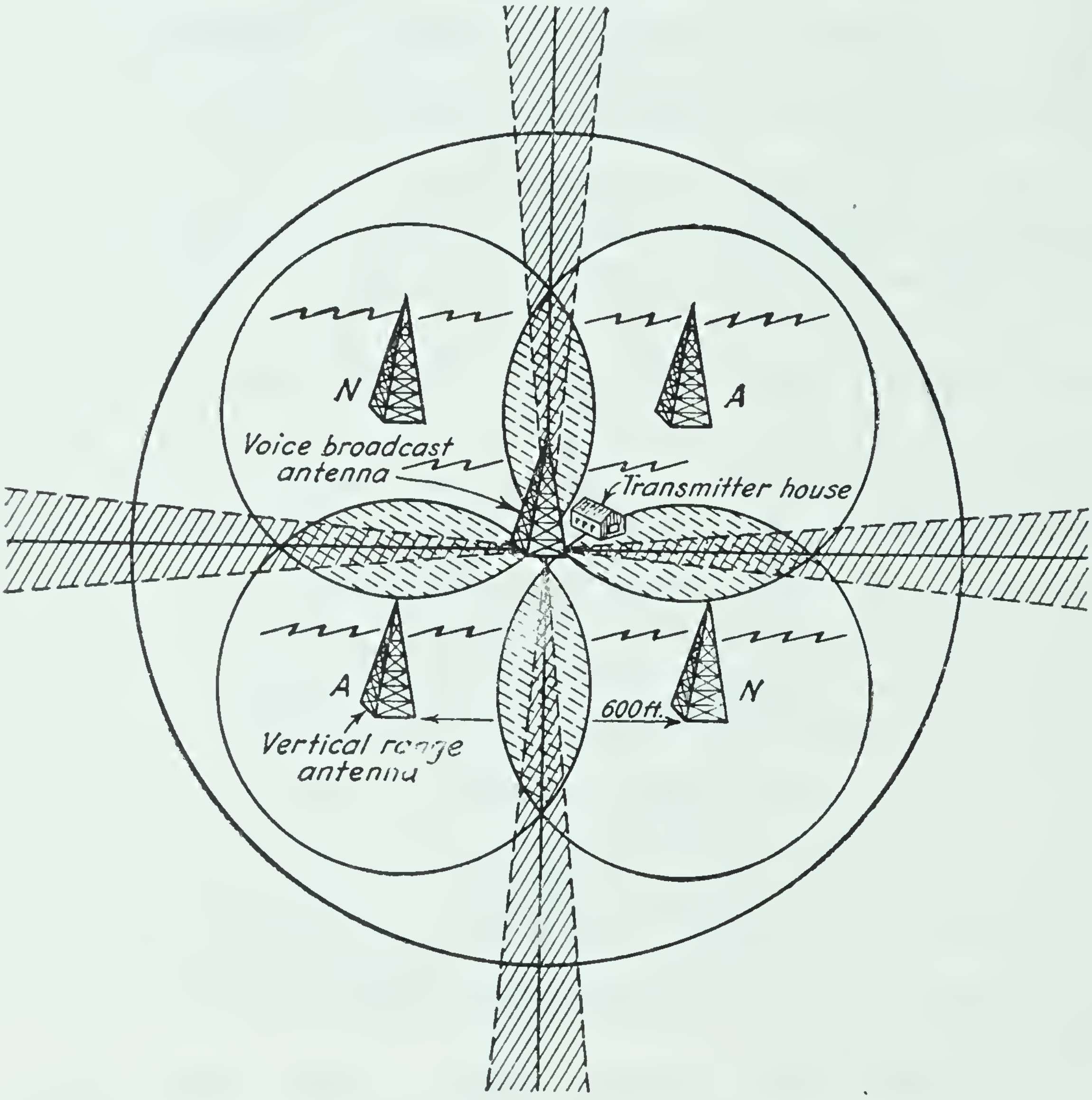


Fig. 250. The simultaneous radio range station

The aeronautical radio range frequency band of 200 to 400 kilocycles, like the entertainment broadcast band of 550 to 1500 kilocycles, must accommodate a great number of stations (Fig. 244). Some interference between stations is unavoidable. In order to eliminate the danger of mistaken identity, each station is assigned an individual identification signal. The range signals are interrupted about every 30 seconds in order to transmit the station-identification signals twice (once from each loop). The wave length or frequency can also be used as an aid in identification of the station.

In addition to the range signals used in flying the course, the pilot receives distinctive signals from low-power marker beacons along the airways. These signals serve to inform the pilot of his progress. In addition, the beacon stations equipped with two-way voice communication can furnish weather reports and other emergency information at the request of the pilot. Airplanes which do not carry a transmitter sometimes signal for transmission of weather reports by circling the station. The pilot indicates that he has received the information by a series of short blasts of his engine. When the marker beacon is located at the junction or intersection of two radio range stations, its signals serve to remind the pilot to tune his receiver to the frequency of the range ahead of him.

The radio compass.

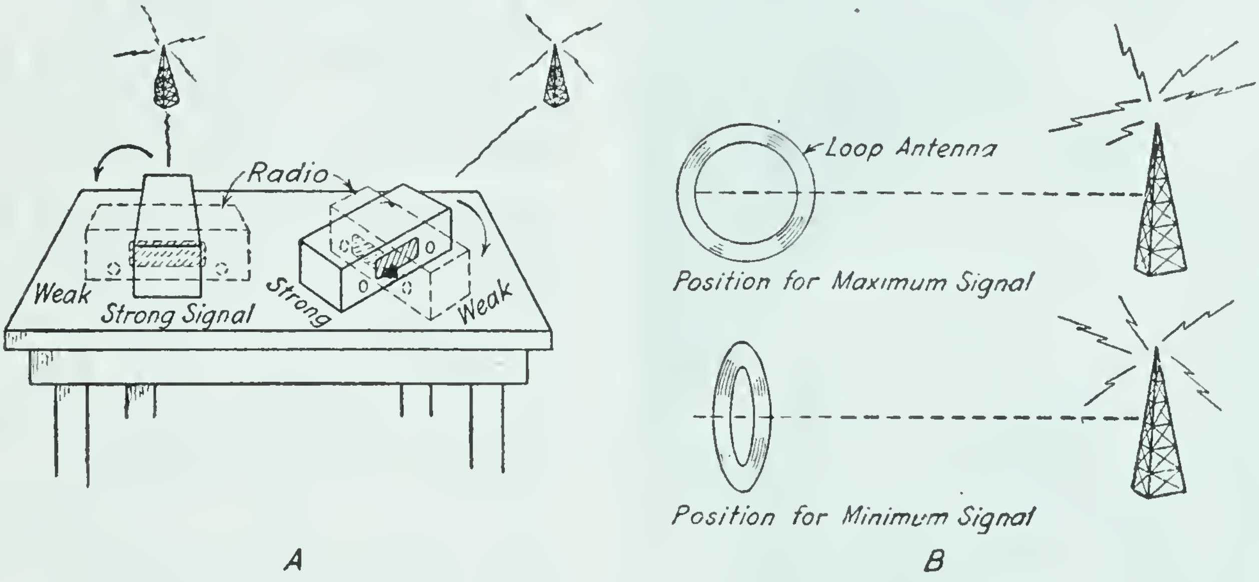


Fig. 251

Laboratory Exercise 45. *Equipment:* Radio receiver with self-contained loop antenna, spark coil, electromagnet, coil, and lamp.

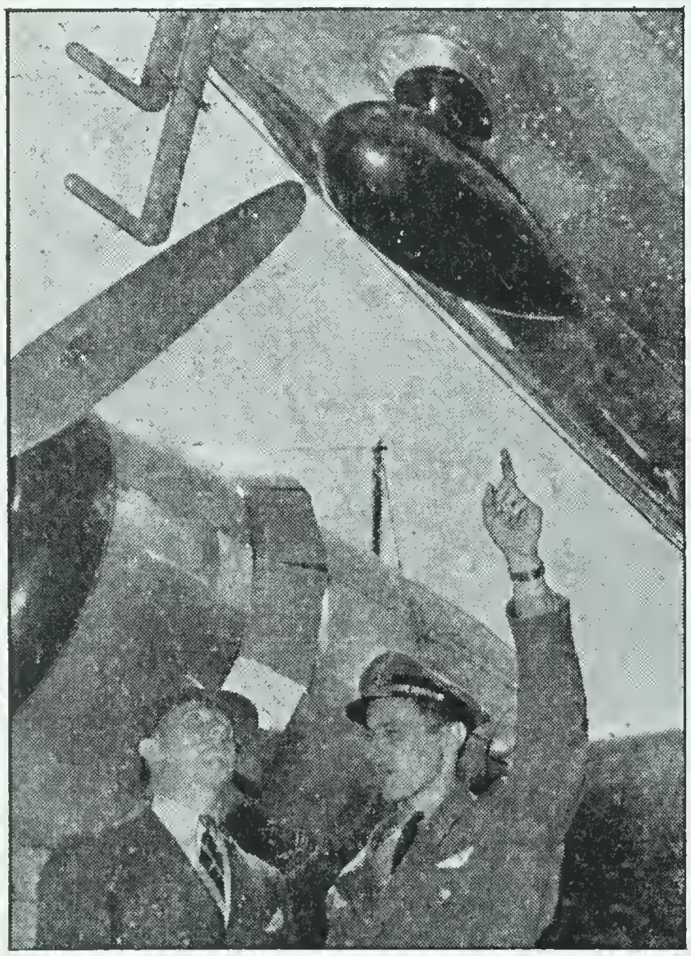
a. Turn on the radio and tune in a station. Turn the radio around slowly. Note any variation in signal strength.

b. Tune in a second station and turn the receiver around slowly. Are the positions of maximum strength the same in each case? Repeat the experiment using a spark coil as the sending station.

c. Move the receiver to a new location in the room, if possible to where steel pipes or steel reinforcements are in the path of the radio waves. Compare positions for maximum strength with those previously noted.

d. If a long-wave tuning receiver is available, tune in radio range signals. Try to determine the direction of the radio range station.

The radio compass and the radio direction finder are two closely related devices which offer additional aid to the pilot in flying a course. In both of these instruments the directive properties of a receiving loop antenna are utilized. A broadcast receiver with a loop antenna represents the simplest form of direction finder. When such a receiver is rotated about a vertical axis, two positions are found at which the signal reception is maximum and two different positions at which the signal strength is minimum. The positions for maximum strength are in each case at right angles to the positions for minimum strength (Fig. 251*a*). The loop antenna of a direction finder consists of many turns of wire wound into a loop which can be rotated through an angle of 360°. The loop may be enclosed in a streamline housing for protection against moisture and for reduction in drag (Fig. 252). The response of the receiver is maximum when the plane of the loop is in line with the transmitting station, and the response is minimum when the axis of the loop is in line with the station (Fig. 251*b*). In determining direction the point of minimum signal strength is used because it can be determined more accurately than the point of maximum strength. In practice this point is obtained by swinging the loop antenna of a direction finder back and forth until the minimum or "null" point is obtained. The bearing of the station with reference to the heading of the plane may then be read from a graduated dial. This procedure may be simplified by use of an automatic direction finder in which an indicating needle points in the direction of the station which is broadcasting.



Courtesy Northeast Air Lines

Fig. 252. Loop antenna on D.C. 3 Airliner used to take bearings with automatic direction finder

The radio compass makes use of a fixed loop with a visual indicator. In this instrument the needle is adjusted to point toward zero when the ship is headed towards the station from which the signal is being received. Any tendency for the ship to depart from its course is instantly shown by a movement of the indicating needle. By use of the radio compass it is possible for the pilot to fly directly to a radio range station from any angle, thus eliminating the extra flying time usually necessary to get "on course." While the radio compass is used chiefly as a "homing device," it is also used in connection with some instrument landing systems. In instrument landing, the pilot, instead of watching the horizon and ground beneath him, guides his plane by the dials of his instrument board. Thousands of landings have been made by use of various systems of instrument landing. The day may not be far away when aircraft can be dispatched to a distant airport with an assurance that through the use of instruments a safe landing can be made even if zero-zero weather conditions prevail.

Exercise 46. Would the width of the beam or "on course" signal zone differ for different pilots? Explain.

Exercise 47. Give two reasons why a pilot flies at the right-hand side of the course.

Exercise 48. Describe variations which occur in a range signal as a pilot flies over a range station.

Exercise 49. Discuss the advantages and disadvantages of both loop and simultaneous range stations.

Exercise 50. What fundamental principle do all direction finders use?

Exercise 51. Why is the "null" position used rather than the maximum signal position to determine the direction of a transmitting station?

Exercise 52. Why are radio receivers used on airplanes equipped to separate voice signals from radio range signals?

Exercise 53. Explain how an "on course" signal is formed.

APPLICATION ACTIVITIES

1. Make a list of ways in which radio waves act like sound waves. Make another list of ways in which sound waves differ from radio waves.
2. List the ways in which radio communication contributes to the safety, economy, and efficiency of aircraft operation.

3. Explain step by step how the instructions given by the traffic manager of an airport are transmitted to the pilot of an incoming plane.

4. In what ways are the directional properties of loop aerials utilized in guiding pilots to an airport?

5. How are radio waves used in marking the highways of the air?

6. List and discuss the various functions of the vacuum tube as employed in radio transmission and reception.

7. Why do practically all radio receivers used in airplanes employ the superheterodyne circuit?

8. Why is it impossible to receive radio range signals on a broadcast receiver?

UNIT VI

FLYING FROM HERE TO THERE

Exploratory Activities

1. When an automobile trip is planned, what use is made of maps? In what respects will an aviator's chart differ from a road map?

2. Is it possible to lay the cover of a baseball out flat? How is a map related to the cover of a baseball? What is the problem that confronts the map maker when he attempts to represent the surface of the earth on a flat map?

3. Have you had an opportunity to examine the instrument panel of an airplane? What instrument dials did you see?

4. Why is it important for the aviator to plan a trip carefully before he takes off?

5. What star groups can you identify? How is a knowledge of the stars likely to be of value to the air navigator?

Overview

After man had learned to fly, his next problem was to learn how to fly safely and economically from one point to another—from take-off to destination. The first aviators navigated simply by the method known as piloting. Using this method they relied on landmarks (such as railroads, highways, or rivers) to guide them on their journey by air. This method seriously handicapped flying, of course, because in bad weather or at night, landmarks could not be seen. Accordingly, research in aviation began to concentrate upon finding aids to air navigation whereby planes could fly expeditiously from one place to another even when natural surface landmarks were not visible.

The science of air navigation developed rapidly. Among the first aids invented were various types of beacon lights which flashed guiding signals in code to aviators.

As the flying range of airplanes increased, dead reckoning became important as a means of air navigation. More adequate charts were prepared for the use of the aviator, and wider use was made of instruments in flight.

The development of the radio range was a distinct forward step in methods of air navigation. Likewise, two-way radio enables the pilot to keep contact with the ground.

Transoceanic flying and substratosphere flying have brought out the need for celestial navigation. An authority on air navigation says, "More and more the aviator will look upward to chart his flight." The methods of ocean navigation have been adapted for use in celestial navigation. The speed of flight in the air has necessitated speed in computation; so the methods of plotting positions have been shortened and improved for air navigation.

The problems of air navigation are treated in this unit. Special attention is given to the development and use of the charts upon which the pilot plots his course. The actual problems of the unit are based upon a portion of the Des Moines Sectional Aeronautical Chart.

Problem 1. How do the form and movements of the earth affect air navigation?

The earth a sphere. The earth's shape is almost spherical. Its diameter at the equator is twenty-seven miles greater than its diameter from pole to pole. The dotted line in Figure 253 shows the form the earth would have if it were a true sphere. The heavy line shows the actual shape of the earth. The difference in the diameters is believed

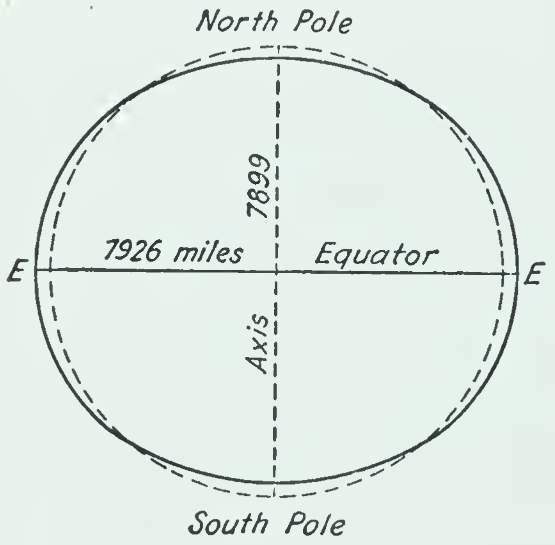


Fig. 253. Rotation makes the earth a spheroid

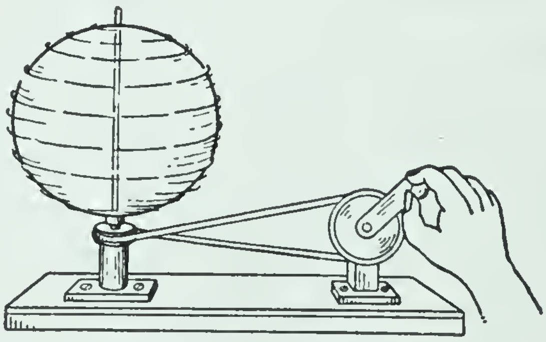


Fig. 254. Centrifugal force causes a hoop to bulge at its equator and flatten at its poles

to be a result of the centrifugal force of the earth's rotation. Figure 254 illustrates what happens when a hoop is revolved about an axis.

The solar system. The earth is a member of the solar system. This system is a family of rotating planets which revolve about the sun. The third member from the sun is the earth, which is nearly 25,000 miles in circumference and maintains an average distance from the sun of about 93,000,000 miles. The earth rotates and revolves with comparative smoothness and uniformity. Since the inhabitants of the earth share in its movement, they are not conscious of it.

Only two motions of the earth are important here—rotation and revolution.

Rotation. The earth spins about its shortest diameter. This diameter is the one that joins the poles. It is referred to as the *axis of rotation.* The direction of rotation is from west to east, and in consequence, the sun, moon, and stars seem to rise in the east. pass across the sky, and set in the west. The rotation of the earth causes this apparent change in the position of the sun, moon, and stars.

The earth makes one complete rotation every twenty-four hours. This period of rotation determines the length of our day. Because the earth receives its light and heat from the sun, the half turned toward the sun has its daylight. When half of the earth is having its daylight, the other half is in shadow and has night. Since the earth rotates, the light gradually moves. Thus in a period of twenty-four hours, every point on the earth's surface has in turn morning, noon, and night (Fig. 255).

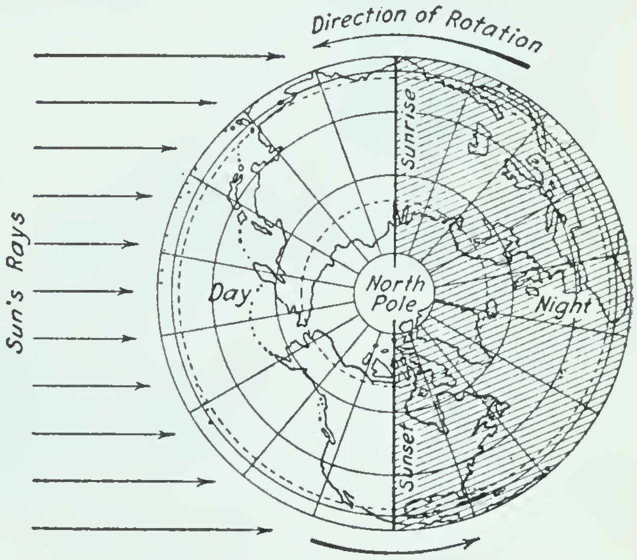


Fig. 255. Rotation causes day and night

Revolution. The earth travels in a path around the sun at the same time that it is rotating about its axis. The path which the earth follows is called its *orbit,* and the journey takes 365¼ days. This period of *revolution* determines the length of the year.

All planets do not revolve about the sun at the same rate. Mercury, the planet nearest the sun, revolves four times faster than the earth; whereas others require scores of years to make the complete trip around the sun.

If the earth's axis were perpendicular to the plane of its path or orbit, our days and nights would be of equal length throughout the year. Any place on the earth's surface would receive the noon rays of the sun at a constant and unchanging angle. However, the earth's axis is 23½° from the perpendicular to the plane of the earth's orbit, and its successive positions always remain parallel. Consequently, the angle at which the sun's rays strike the earth at any point varies as the earth revolves in its orbit, thus giving us unequal hours of daylight and darkness. At the equator the longest period of daylight is twelve hours. Figure 256 illustrates how the length of the longest period of daylight increases as one moves northward, until at the north pole it is six months in length. Obviously, a similar change occurs as one moves southward from the equator.

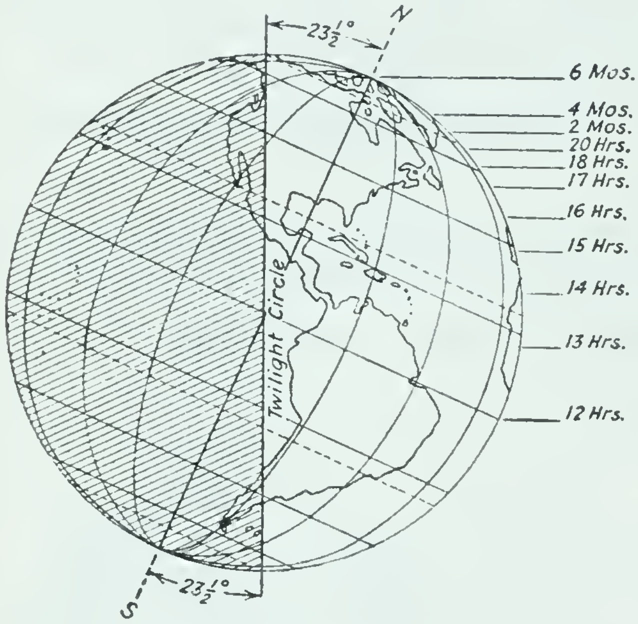


Fig. 256. The length of the day

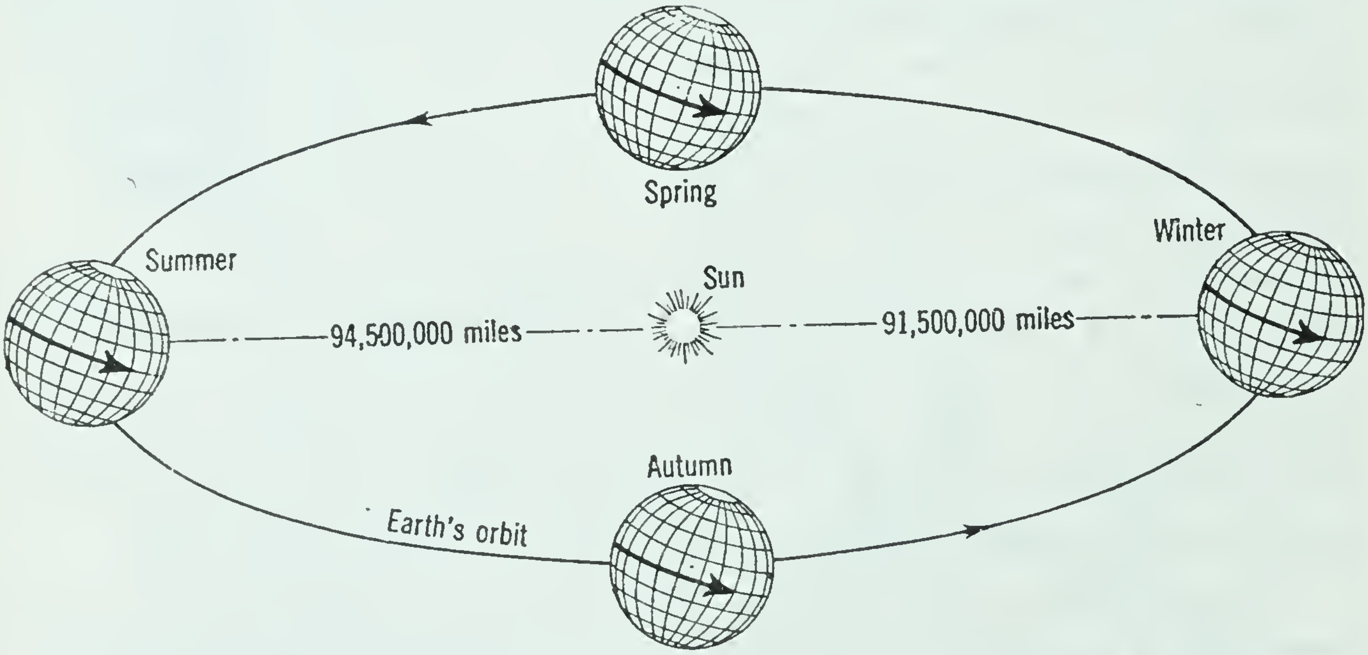


Fig. 257. Positions of the earth showing seasons for the northern hemisphere

The change in seasons depends upon the inclination of the earth's axis and the revolution of the earth about the sun. Because of the inclination of the earth's axis, the sun's rays strike the earth less directly in winter than in summer. The sun is also lower in the heavens in winter and gives us our shorter days. If the earth's axis was inclined at more than 23½°, the seasons would be more pronounced—the winters would be colder, and the summers would be warmer.

The length of the seasons results from the parallelism of the earth's axis and the time of revolution. If the earth required more time to go around the sun, the seasons would be longer. In Figure 257 the earth is shown in the position it assumes at the beginning of each season.

Laboratory Exercise 1. Make use of a globe and the illustrations shown in Figures 258, 259, and 260 to work out the following exercises:

a. What is the inclination of the earth's axis?

b. What has inclination to do with producing the seasons?

c. Why do places in the northern hemisphere have their longest day on June 21?

d. Why are seasons north and south of the equator reversed?

e. On what two days are the rays of the sun perpendicular to the earth's axis?

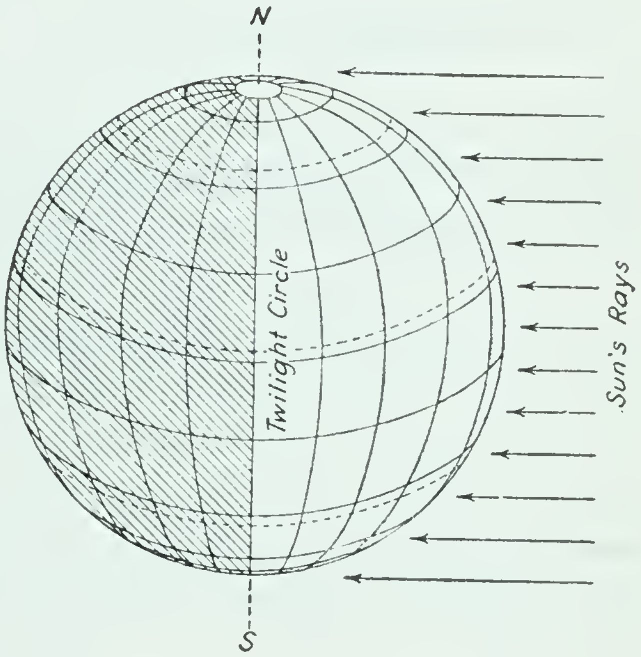


Fig. 258. Position of the earth September 23 and March 21. In some years the earth may reach this position on September 22.

f. What portion of the earth's surface has sunlight at any given moment?

g. Which city has more hours of sunlight during the summer: Minneapolis or New Orleans?

Latitude. On a flat surface it is convenient to locate points with respect to two reference lines at right angles to each other. For example, in Figure 261 the point *P* may be definitely located when its direction and distance from *XX′* and from *YY′* is known.

In a similar manner, if two intersecting lines of reference can be established on a sphere, points on the sphere can be located. The axis about which the earth rotates is a line within the sphere different from any other diameter. We select this axis, marked by the north and south poles, as our primary line of reference. We make use of this, and the next step is to establish a line on the surface of the earth. For convenience we choose that line (or circle) on the earth's surface the plane of which will cut the axis in half. This circle is the *equator*.

If we should fly from the equator to the north pole, we would cover one fourth of the distance around the earth. It is common to think of circles as being divided into 360 degrees. This means that we can think of distance from the equator to a pole as containing 90 degrees. We can locate points north or south of the equator by drawing circles parallel to it. These parallel circles are known as *parallels of latitude.* As their distance from the equator increases, these circles decrease in diameter until, at the poles, a circle of latitude is reduced to a point. The equator is called 0° latitude; the north pole, 90° north latitude; and the south pole, 90° south latitude. The position of any point on the sphere with respect to latitude may now be definitely given as so many degrees north or south of the equator. For example, a point 5 degrees north of the equator is designated Lat. 5° *N.*

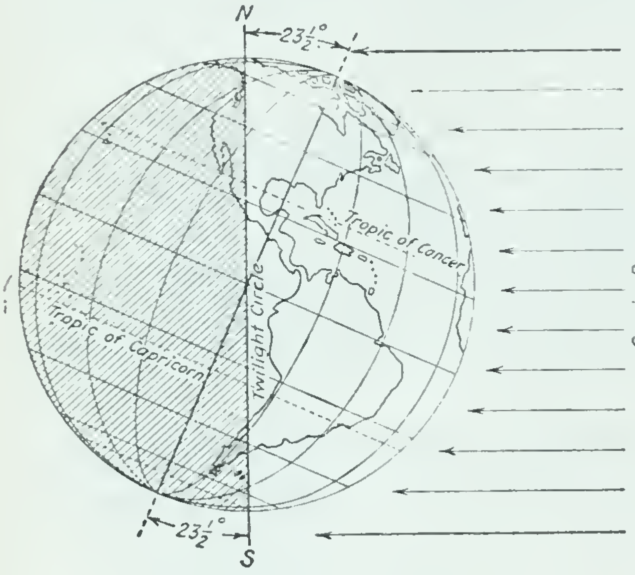


Fig. 259. Position of earth June 21

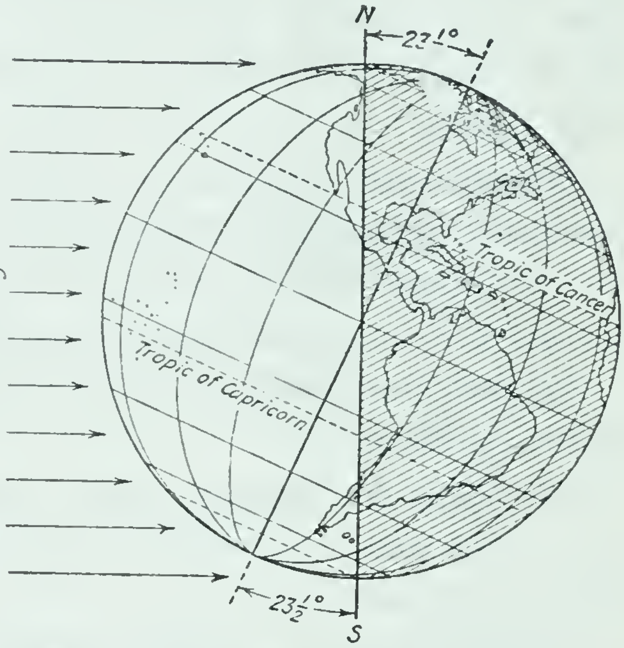


Fig. 260. Position of earth December 21

The length of a degree of latitude varies slightly because the earth is not a perfect sphere. At the equator a degree is about 68.7 miles; at the poles, it is about 69.4 miles. For practical purposes we may think of the degree of latitude as being 69 miles.

On a small map it is customary to draw parallels 5 or 10 degrees apart. However, on a map such as the sectional aeronautical chart, parallels are drawn much closer together. For example, on the portion of the Des Moines chart we find the parallels represented for 41°, 41°30′, and 42°.

Longitude. The next problem is to locate points with respect to their position east and west of each other. Again we refer to the poles and draw circles which pass through them. These circles, known as *lines of longitude,* meet at the poles and are the greatest distance apart at the equator. The name *meridian* is often applied to them. The degrees of longitude vary greatly in length. At the equator a degree of longitude is about equal to a degree of latitude (69 miles). This distance steadily decreases toward the poles; in latitude 60° a degree of longitude is about 34.7 miles; and at the poles a degree of longitude has no length.

For the measurement of longitude, we must determine some starting point. A great many places have been used by different nations for this purpose. The English adopted the meridian passing through their principal observatory at Greenwich as the origin for reckoning longitude. This has been adopted by many countries including the United States. This meridian is known as the Prime Meridian.

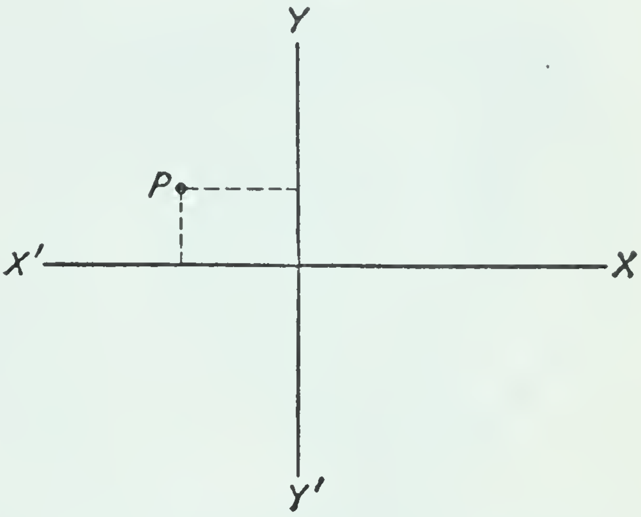


Fig. 261. Location of a point from known reference lines

The longitude of a place may be expressed in several different ways. These are:

1. The distance along the equator, measured in degrees, minutes, and seconds between the meridian of Greenwich and the meridian passing through the place
2. The distance from the meridian of Greenwich, measured along the parallel passing through the place in degrees, minutes, and seconds
3. The angle at the pole between the meridian of Greenwich and the meridian passing through the place.

These become similar when we realize that the angular distance measured in degrees is the same in each instance. The distance in miles is different. For that reason we do not attempt to translate degrees of longitude into miles.

The Greenwich meridian, if it is considered to be continued completely around the world, divides the equator into two semicircles of 180° each. Longitude is measured east and west beginning at 0°. where the Prime Meridian cuts the equator south of Greenwich and continues 180° to the point where it cuts the equator on the opposite side of the earth. We can locate points by saying they are so many degrees east or west of the Prime Meridian. For example, Niagara Falls is Long. 79° *W.*

We have now established two reference lines on the surface of the earth — the equator for latitude, and the meridian of Greenwich for longitude. A point on the earth may now be definitely located by giving its direction and distance in degrees from these two lines. For example, we might say that the position of New York City is 40°46′47″ *N.,* 73°58′41″ *W.* Figure 262 illustrates how the reference lines would appear on a graph.

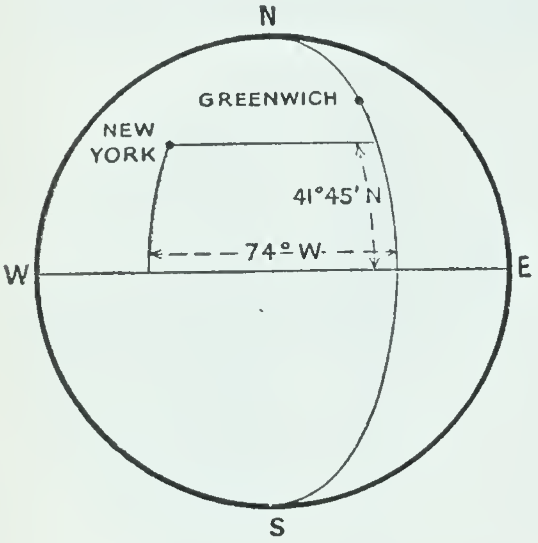


Fig. 262. Locating a point on the earth's surface

The sun and time. The sun appears to pass around the earth once every twenty-four hours. When the sun crosses the meridian of any particular place, it is noon there. At that same instant it is one o'clock P.M. at a point 15° longitude east of this place, and eleven o'clock A.M. 15° west. The time at any place, as read from a sundial, is called sun time, or local time. Since our days vary in length, man has decided to take the average length of all days in the year and call this time period the mean (average) solar day. Clocks keep mean solar time; whereas the sundial shows actual solar time.

If every community set its clocks to correspond with the reading on the local sundial, we should find a different local time for every place as we traveled east or west. In fact, back in the days when travel was slow, every city had its own local time. This system of having neighboring cities vary a few minutes or a few seconds in time according to their longitude was confusing, once people began to travel by railroad. Consequently, in 1883, the American railways adopted a system of standard time. The system established time belts approximately 15° in width, and every place within that belt had the same time — standard time. The width of the belt was easy to determine because the earth rotates through 360° of space every twenty-four

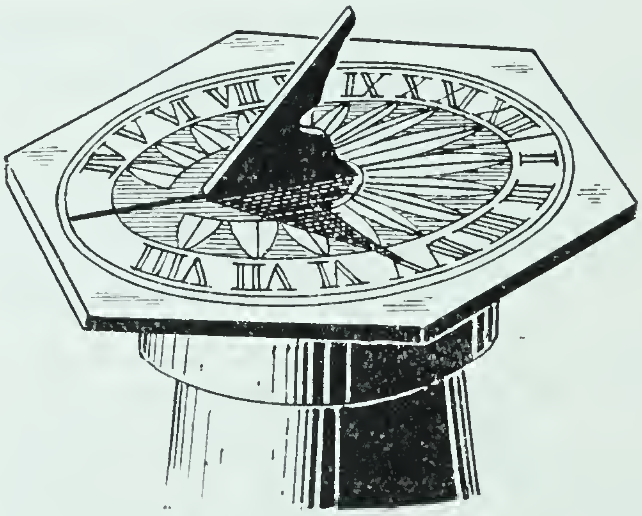


Fig. 263. Sundial

hours or through 15° every hour. As one travels east, he sets his watch ahead one hour upon entering a new standard-time belt, and if he travels west into another time belt, he sets his watch back one hour.

In summer the days are longer than in winter. In order to take advantage of the sunlight many cities advance their clocks one hour in the spring. They then have daylight-saving time. Thus a person goes to work one hour earlier in the morning and leaves his work one hour earlier in the evening. This permits thousands of city people to enjoy hours of outdoor leisure in the sun. In the fall, when the days become shorter, the city returns to standard time.

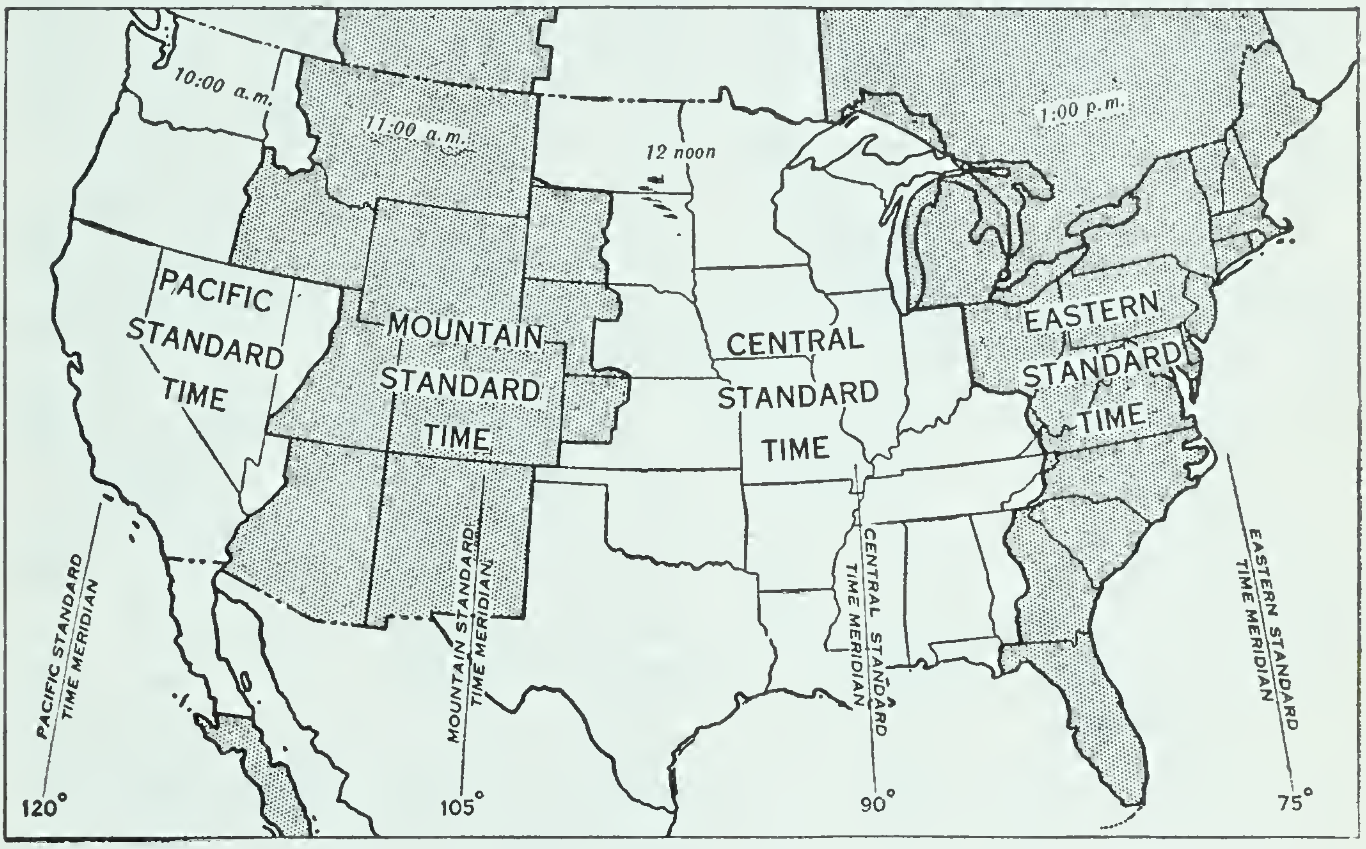


Fig. 264. Standard time zones of the United States

Time and flight. If an aviator were to fly westward around the earth he would need to set his watch back one hour for each 15° traveled—a total of twenty-four hours. Upon his return he would be one day behind an individual who had stayed at home. If he were to fly east, he would find himself one day ahead. It is therefore not enough, in traveling around the earth, to move one's watch an hour forward or backward upon entering a new standard-time zone. The day of the week and the day of the month must also be changed somewhere in the course of a round-the-world trip. To avoid confusion the 180th meridian, which is located in the middle of the Pacific Ocean, has been designated as the place where the changes of date

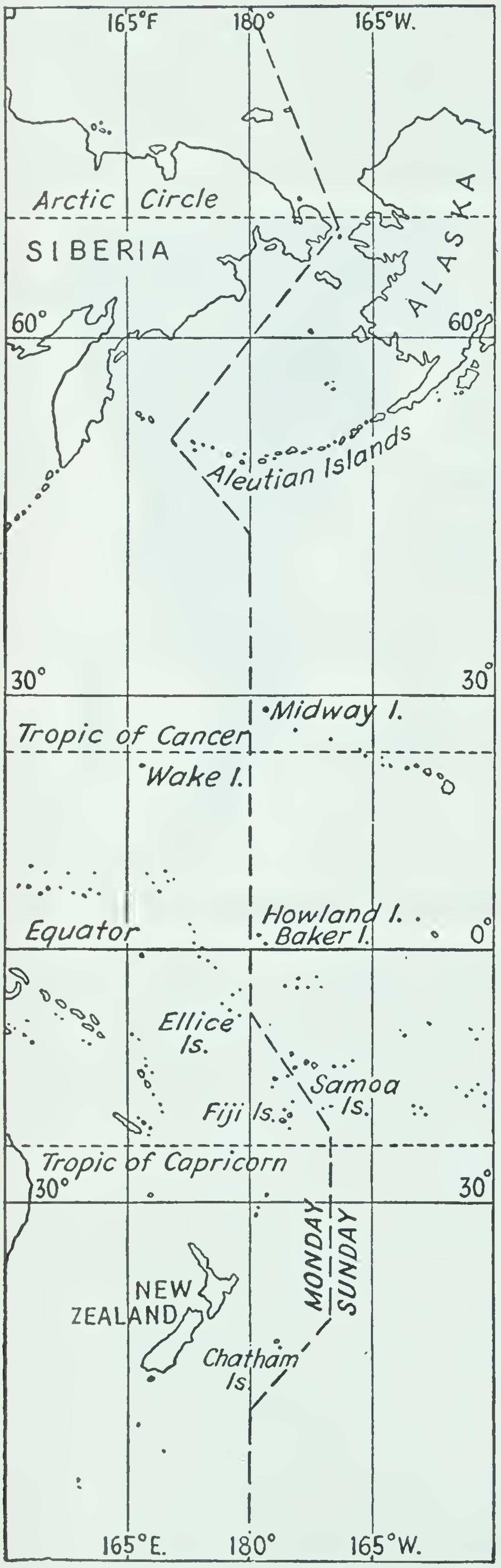


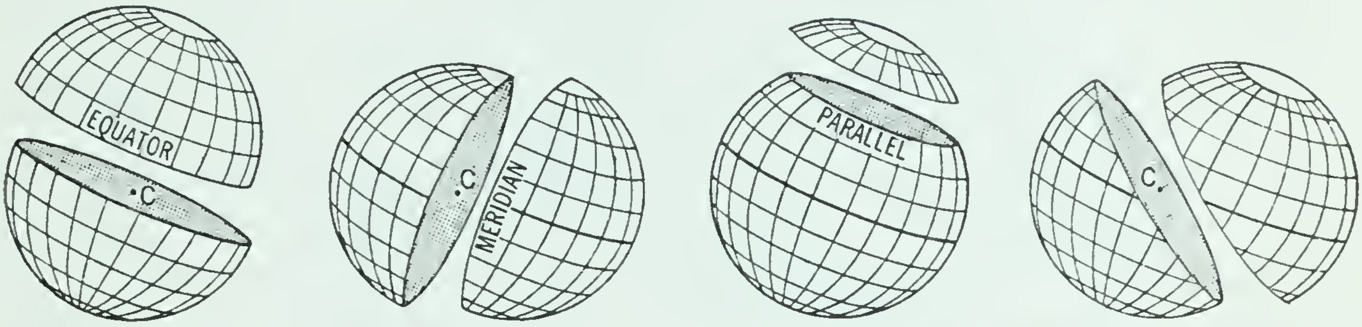
Fig. 265. The international date line

take place. Figure 265 shows how the date line is bent so that it does not pass through any large important land areas.

In celestial navigation, time is kept on a twenty-four-hour basis. Thus, 9 A.M. is 900, 4 P.M. 1600, and 7:30 P.M. is 1930. This is the way in which time is tabulated in the Air Almanac. The United States Army and Navy also designate time on a twenty-four-hour basis.

Pilots are required to report their estimated time of arrival to the airway-traffic control center. In order to avoid confusion that might be caused by adding an hour when it should have been subtracted, or vice versa, it is standard practice to report according to the watch time kept by the pilot. The estimated time of arrival, for example, should be given as "3:00 P.M., central standard time," even though the destination is in another time belt. Then there can be no doubt in the mind of the pilot or control-tower operator concerning the time.

Distance on a sphere. Methods of determining distances are based upon the spherical shape of the earth. In plane geometry we learned that a straight line is the shortest distance between two points. In solid geometry we learn that the arc of a great circle is the shortest distance between two points on the surface of a sphere. Since the shortest distance between two points on the earth is the great-circle route, we may say that the great circle is the straight line of the sphere. Now just what is a great circle? Simply expressed, a *great circle* is a circle around the sphere such that any diameter of the circle passes through the center of the sphere. In fact, if we should cut the earth in two parts along a great circle, we would divide it into two hemispheres. The equator is a great circle, and so are all the meridians. There can, of course, be any number of great circles besides these special ones.



The equator is a great circle.

Any meridian is a great circle.

A parallel is NOT a great circle.

Any plane passing through the center of the earth cuts the surface in a great circle.

C = center of the earth

Fig. 266. Great circles on the earth

Except for the equator, parallels of latitude do not divide the earth into equal parts. A parallel is, therefore, not a great circle. Regardless of its size, any circle on a sphere is called a small circle if all diameters of it do not pass through the center. Parallels are thus small circles. The plane of a small circle does not pass through the center of the spheroid. Figure 266 illustrates the foregoing definitions.

Distance along a great circle is measured in degrees, minutes, and seconds of arc. This distance is then converted into nautical miles or statute miles. A nautical mile, for practical purposes, is a minute of latitude or a minute of any other great circle. The flattening of the earth near the poles causes the length of a minute of latitude to vary somewhat. In the United States, however, a nautical mile has been definitely fixed at 6080.20 feet. The nautical mile is always used in ocean navigation. The statute mile is commonly used on land and for air navigation over land. The scales printed on the Sectional and Regional Aeronautical charts are based upon the statute mile of 5280 feet. (The scale on the sectional charts is approximately eight miles to the inch; whereas the scale on the regional charts is about sixteen miles to the inch.)

Navigators of ships are often able to follow a constant compass course for a full day's run. The line traced by this constant course is known as a *rhumb line*. A rhumb line is a line on the earth's surface which cuts all meridians at the same angle. If a navigator follows a rhumb line indefinitely, he will travel in a long spiral and approach one of the poles. By examining Figure 267 we can see that the rhumb-line course is not so short as a great-circle course. It does have the advantage of following one compass reading for a full-day's run.

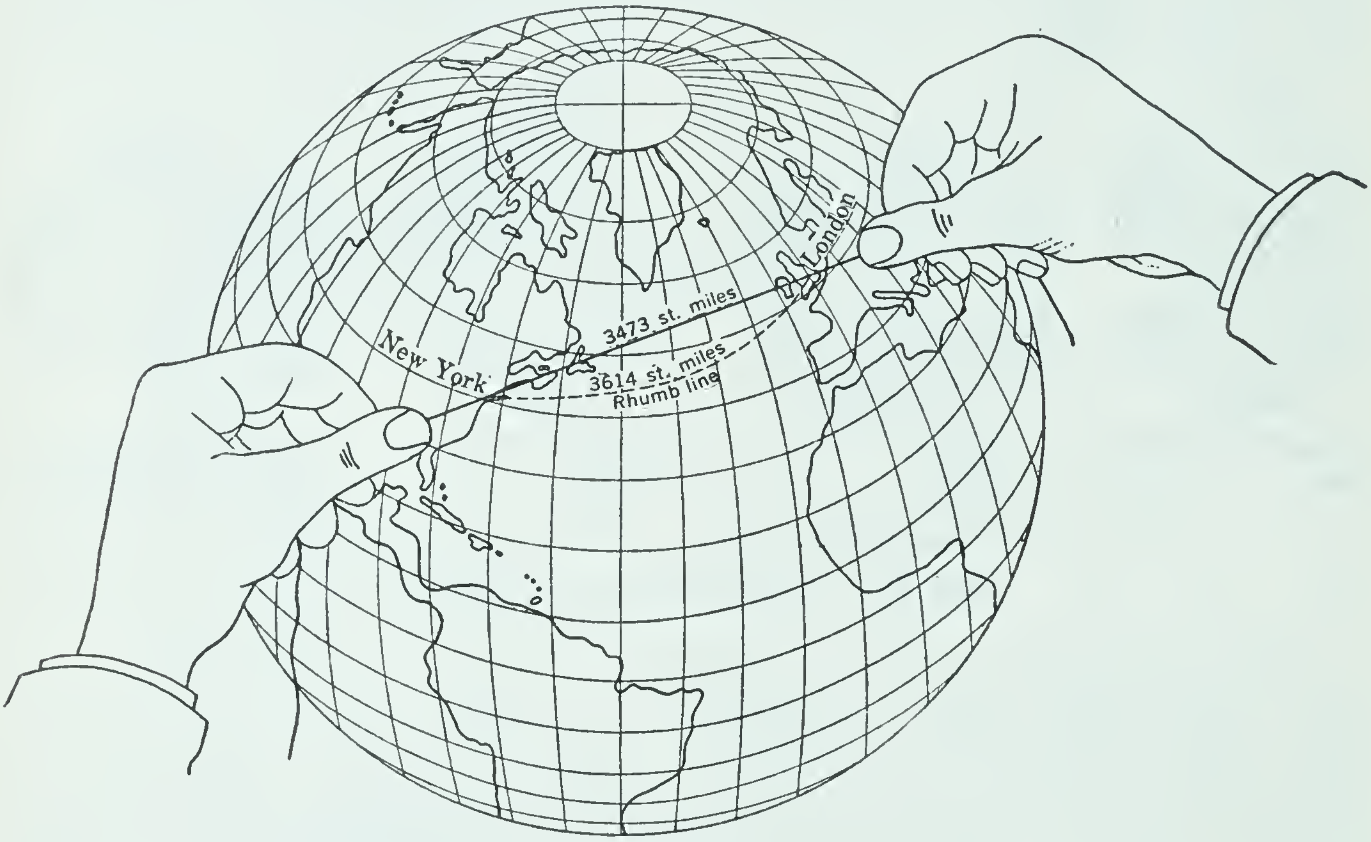


Fig. 267. A great-circle route compared with a rhumb-line route

Exercise 2. Define air navigation.

Exercise 3. How does the rhumb line differ from the great-circle route between two points?

Exercise 4. What is the reason for the difference between the polar and the equatorial diameters of the earth?

Exercise 5. Explain the meaning of latitude and longitiude.

Exercise 6. Name the standard-time zones of the United States.

Exercise 7. What is the difference between a great circle and a small circle on the earth?

Exercise 8. What is the relationship between a nautical mile and a statute mile?

Exercise 9. Why is a Prime Meridian necessary?

Exercise 10. If it is 1600 on Long. 60° E., what is the local time on Long. 30° W.?

Problem 2. What must the aviator know about map projections?

Mapping a sphere. An accurate globe is the only true representation of the earth. One who studies a globe will acquire an accurate picture of the shape, size, and position of the earth's features. It is not convenient, however, for the aviator to carry a globe. He needs flat maps.

It is difficult to represent the curved surface of the earth or any portion of it on a flat, or plane, surface. No portion of a sphere can be flattened out into a plane without some stretching or tearing. For example, it is impossible to spread out the cover of a baseball, a cap of orange peel, or a portion of a hollow rubber ball so that the central part will be in the same plane with the outer part without some stretching and tearing of the curved surface. This stretching or tearing is accompanied by distortion. This is exactly the same difficulty that the map-maker has when he undertakes to present the features of the earth on a flat map.

There are some curved surfaces which can be spread out into a plane without stretching or tearing them. The surface of a cylinder, for example, when cut from base to base can be rolled out into a plane. Likewise a conical surface, when cut from base to apex, can be flattened out into a plane.

The Mercator projection. A flat map which has been used widely for many, many years was first invented by Gerhard Krämer. This map is known as the *Mercator projection.* It is thought that the inventor devised his map in the following manner: He probably took a spherical object and with a pair of scissors cut the curved surface along improvised meridians, cutting from the poles toward the equator. Only at one place, however, did he cut completely across the equator. It was now possible for him to flatten out his map. This map was unsatisfactory because it showed vacant spaces above and below the equator. In order to eliminate the vacant spaces he joined the triangular sections (gores) along the meridians. This introduced exaggeration, however, into his projection. This exaggeration increased as the poles were reached. Therefore, in order to balance the map, he distorted latitude as he had distorted longitude. He thus was able to restore the balance of any part of the map as to shape.

An important feature of the Mercator projection map is that the meridians are shown as parallel lines and the lines of latitude cross them at right angles. Every parallel is shown as having the same length as the equator, and the meridians are extended in proportion to the parallels. On the globe the parallel of 60° north or south is half as long as the equator, but on the Mercator projection it is represented as having the same length.

Within 30° of the equator the Mercator projection does not offer serious exaggeration in area or shape. But any portion of the earth's surface located 60° north or south of the equator would be shown on a Mercator map as being four times its true size. Greenland, for example, on this map appears to be as large as South America, when, in fact, South America is nine times as large.

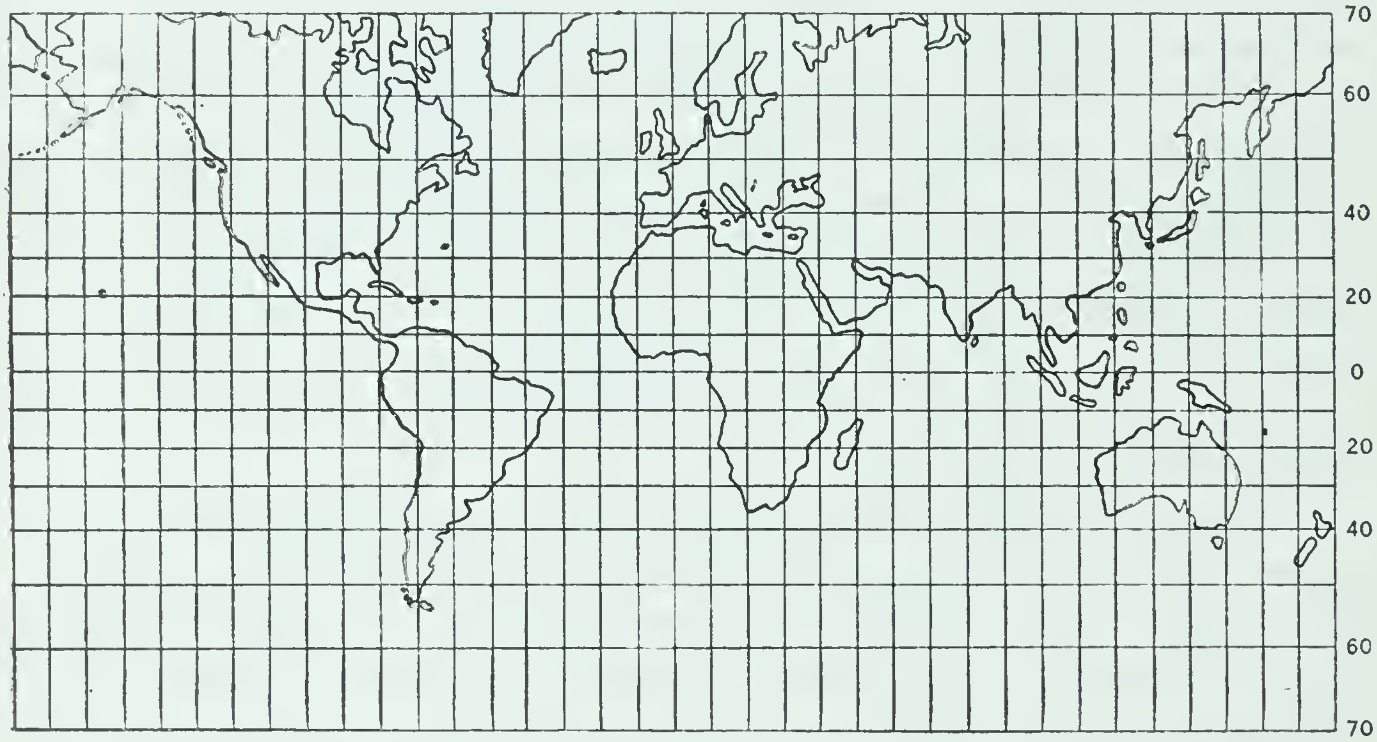


Fig. 268. Mercator's projection of the world

Since parallels and meridians are straight lines on a Mercator projection, rhumb lines are also shown as straight lines rather than as curved lines. For this reason the navigator of a ship finds the projection a convenient one upon which to establish his course. He simply draws a straight line from his location to his destination, measures the angle which this line makes with a parallel or meridian, and steers his course according to this rhumb line. Although such a course is not the shortest route, it enables the ship navigator easily to determine and plot his bearings. The fact that the rhumb line is not the shortest distance between two points on the earth's surface is one reason why air navigators use another projection.

We conclude, therefore, that if the aviator is to use the Mercator map he should keep the following facts in mind:

1. Parallels and meridians meet at right angles.

2. Within the low latitudes the map is accurate enough for general use.

3. In the higher latitudes areas are greatly enlarged.

The Lambert conformal projection. When the Coast and Geodetic Survey was asked to prepare charts for air navigation they decided to use the *Lambert projection.* This projection was adopted by the Allies for their military maps during World War I because it afforded maximum accuracy of directions and distances.

Determining direction and distance is the basic problem of all navigation. A course can be plotted quickly on a Lambert map.

Figures 269 and 270 show the principle of the Lambert projection and an outline map of the United States produced by this method. The cone intersects the surface of the earth along two standard parallels. The standard parallels of true scale adopted for all aeronautical charts of the United States are latitudes 33° and 45°. At all points halfway between these two parallels, the scale error is about one half of one per cent. The scale error is so small that the aviator can disregard it in plotting his course.

The meridians of the earth are represented by straight lines which converge toward a common point (the apex of the cone). The parallels are represented by the arcs of concentric circles. Meridians and parallels intersect at right angles.

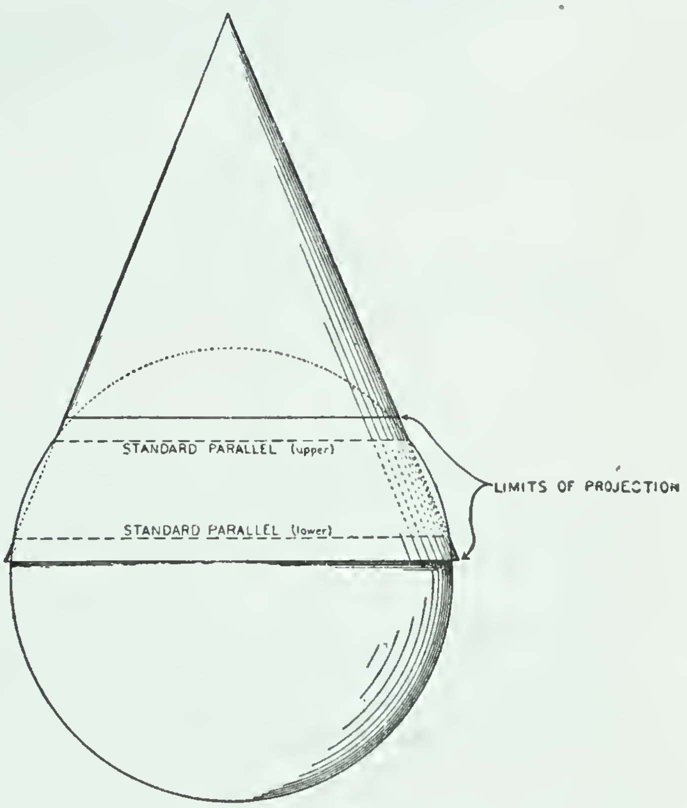


Fig. 269. The Lambert conformal conic projection. Observe that the globe is actually cut at two parallels.

The air navigator plots his course on this projection by drawing a straight line from where he is to where he wants to go, measures the angle at which this course line intersects a meridian, and steers his course accordingly. A straight line on the Lambert map is almost, but not quite, the shortest distance between two points.

The Lambert projection is valuable because:

1. It gives the most accurate shape to areas of continental size, particularly to those of maximum east-west extent.

2. A straight line on this projection for all practical purposes may be regarded as the shortest distance between two points.

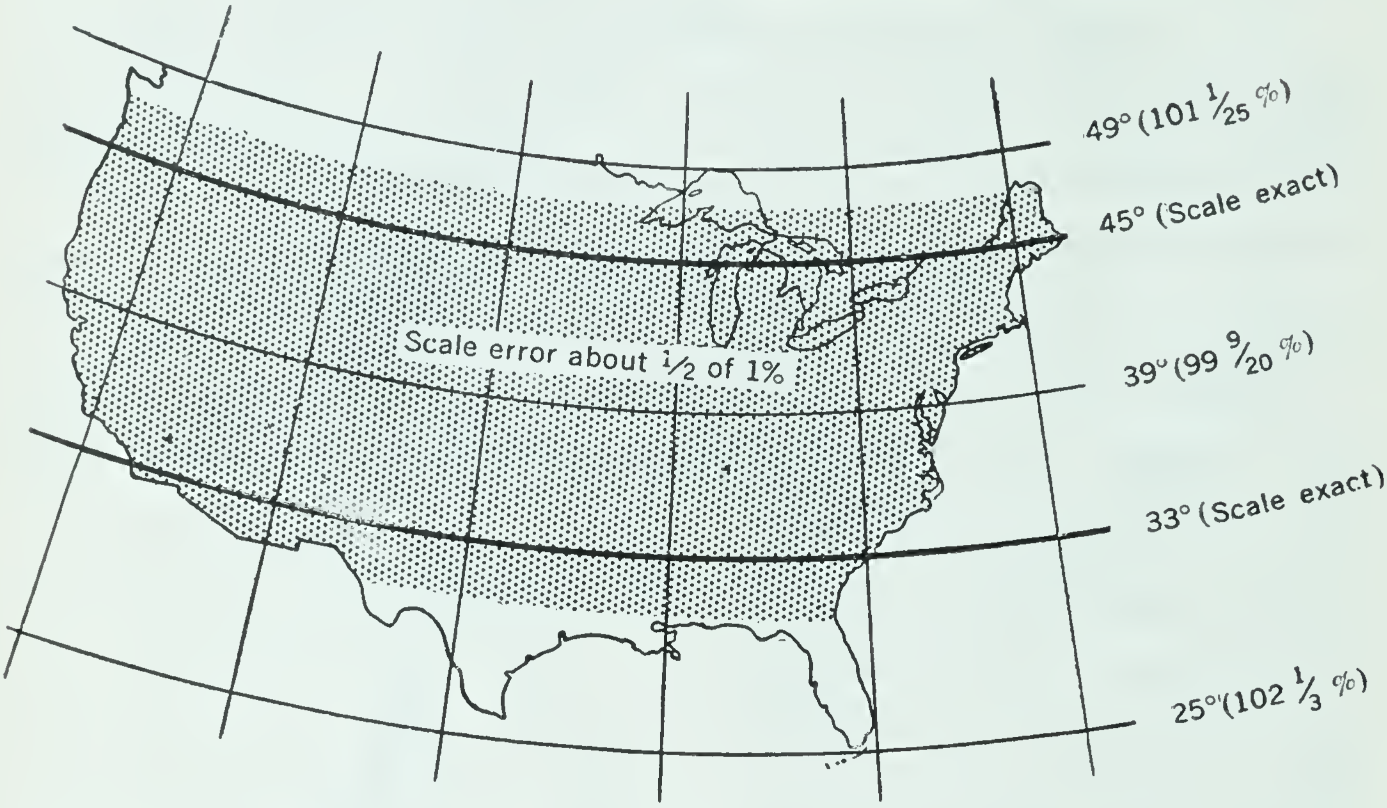


Fig. 270. An outline map of the United States developed on a Lambert projection

It is possible to plot a precise great-circle route on the Lambert projection, but for all practical purposes a straight line on this projection is a sufficiently close approximation of the path of a great circle.

Exercise 11. List the useful features of the Mercator projection.

Exercise 12. Explain the principle of the Lambert projection.

The gnomonic projection. The map-maker has in his *gnomonic projection* a chart upon which the straight line between two points represents the arc of a great circle and is, therefore, the shortest distance between these points. Gnomonic charts are used extensively in planning routes along great circles and are, therefore, sometimes called great-circle charts. This projection is of utmost value in charting long trips. Since shapes and areas are distorted by this method, it does not picture accurately the shapes and sizes of regions.

In the gnomonic projection the observer's eye is conceived to be the center of the earth. Thus it is in the plane of every great circle of the sphere. All great circles of the sphere including the meridians are projected as straight lines on the plane of projection which is tangent to the earth at some given point. Thus the straight lines are great circles and mark off the shortest distance between two points.

The gnomonic or great-circle chart should not be used for courses or distances after the aviator plots his route. The route should be transferred, point by point, from the great-circle chart to the Lambert chart, and the courses and the distances to be flown should be scaled from them.

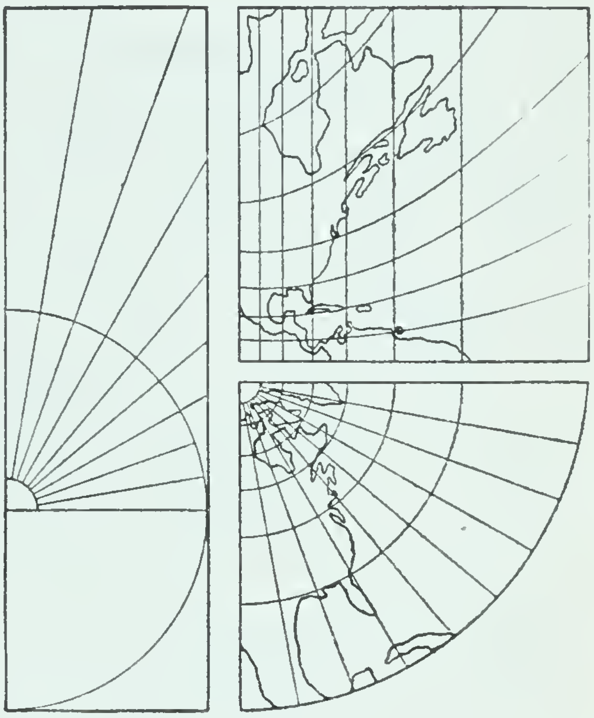


Fig. 271. The gnomonic projection. *Upper:* equatorial. *Lower:* polar.

Summary. For all ordinary purposes the air navigator plots his course on the Lambert chart. Although a straight line is not a precise great circle, it is a sufficiently close approximation for all practical purposes. Courses and distances may be most readily determined from it, and for plotting navigational problems it therefore affords the greatest speed—a most vital element in air navigation.

Problem 3. How do maps and charts aid the aviator?

Available maps and charts. In the early days of air navigation, pilots realized the need for some sort of map or chart. Landmarks in unfamiliar regions could be identified only by referring to a chart. In addition, the position and course of the plane could be checked by using charts.

The Air Commerce Act of 1926 provided for the charting of airways and the publication of aviation maps necessary for safety in flying. The task of preparing these charts of the airways was assigned to the United States Coast and Geodetic Survey with instructions "to provide as adequate charts for air navigation as it now provides for ocean navigation."

Three principal series of aeronautical charts are now being published. The *sectional* charts have a scale of 1:500,000 or about eight miles to the inch. Eighty-seven charts are required to cover the entire United States. The average chart is about twenty by forty-two inches in size. This series is of particular value to the aviator who flies a small airplane by reference to visible landmarks. Figure 272 shows the areas covered by the sectional charts. Each chart is named for a city (or prominent natural feature) which is found within its borders.

Regional charts have a scale of 1:1,000,000 or about sixteen miles to the inch. These charts are called the *M series,* and seventeen of them cover the whole country. They are designed especially for air navigation (by dead reckoning or other methods) as contrasted with piloting. Since these charts cover considerably more area than the sectional charts, pilots using them do not need to change charts as often while in the air. They are often more convenient to use in planning routes that extend beyond the limits of a sectional chart. Figure 273 shows the areas covered by the regional series.

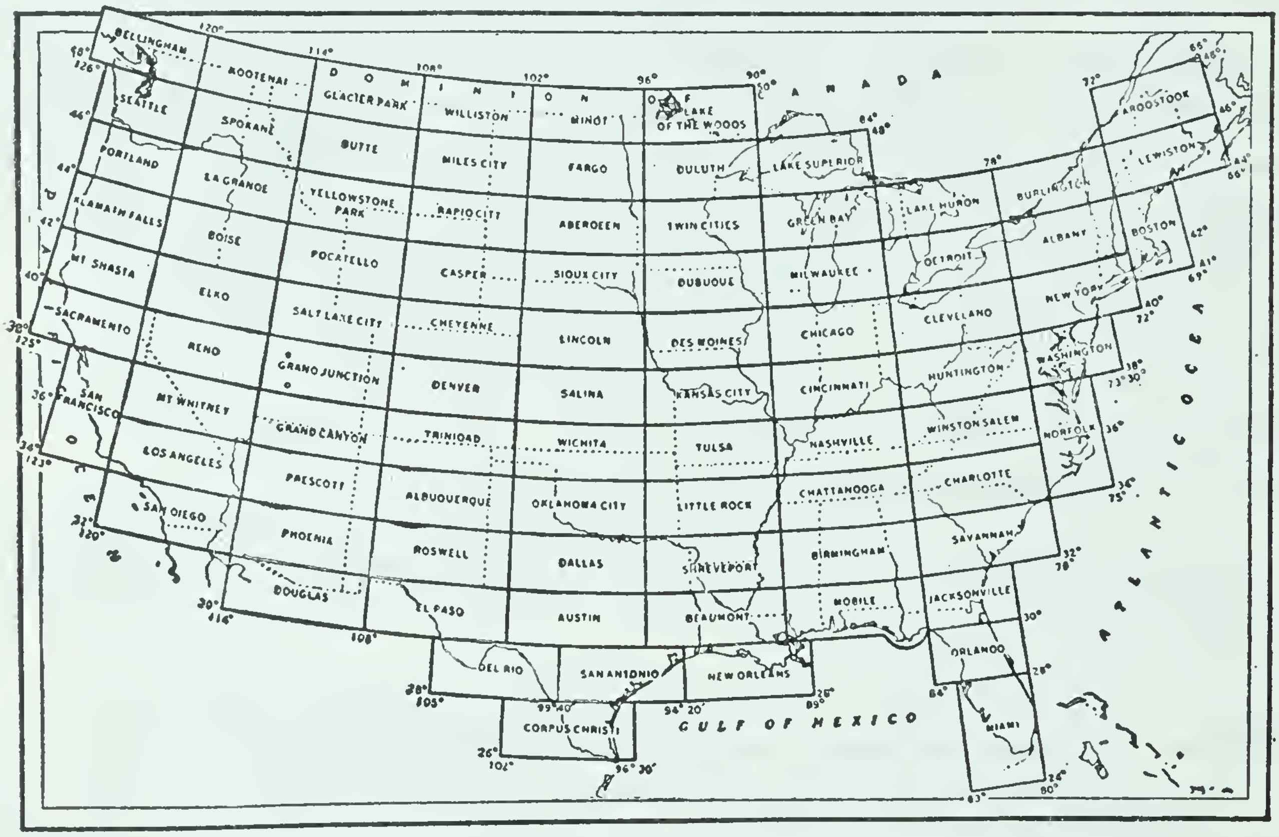


Fig. 272. Index of sectional aeronautical charts

The third group is the *DF* series. These are the *radio-direction-finding* charts. They are constructed on a scale of 1:2,000,000, or about thirty-two miles to the inch. Six of these are required to cover the United States. The *DF* charts are designed for use in plotting radio bearings; their smaller scale makes it possible to plot bearings from radio stations that would be outside the limits of a sectional chart.

In addition to the three principal series, three special charts of the United States are also available. They are: the *aeronautical-planning* chart, which is useful in planning routes between distant points; the *great-circle* chart, which is useful only in determining a great-circle route between two points a great distance apart; and the *mag-*

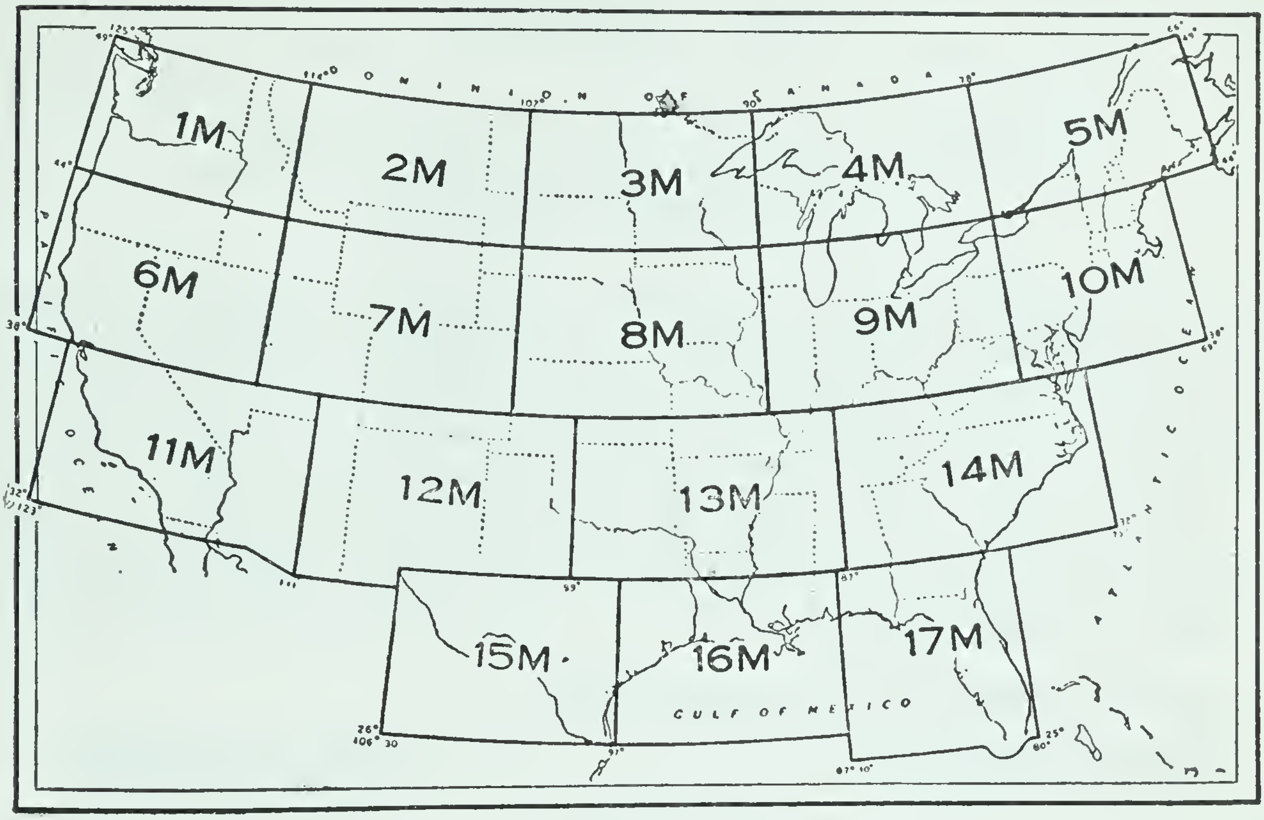


Fig. 273. Index of regional aeronautical charts

netic chart, which shows lines of equal magnetic variation in the United States.

Use of air navigation charts. Much of the information that people have about the surface of the earth has been secured by the study of maps. Maps and charts are placed in textbooks, newspapers, current magazines, books of travel, and advertisements. The aviator realizes the importance of locating places by reference to a chart or map. All kinds of maps and charts have points of similarity. Aeronautical charts, however, contain certain kinds of information that will not be found on other maps. Since each chart has been developed for a special purpose it is accompanied by a legend peculiar to it which explains the symbols that are used. The legend is printed on the bottom of aeronautical charts, and in this book on pages 348-349.

The purpose of this section is to provide information and activities related to the interpretation and use of the aeronautical charts. A portion of the sectional chart for the Des Moines area has been selected to illustrate the problem. Symbols used on the sectional and regional charts are the same with the exception that many of the details are omitted on the regional charts.

Map symbols. At this point the student should begin his study of the Des Moines Aeronautical chart. The following paragraphs explain step by step the procedure which should be followed. The

DES MOINES

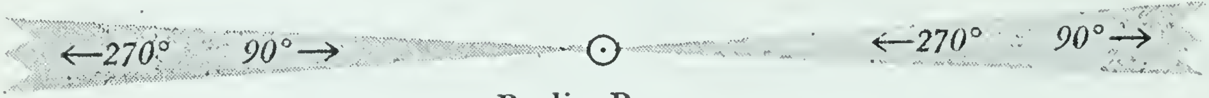
COMPILED AND PRINTED AT WASHINGTON, D. C.
BY THE U. S. COAST AND GEODETIC SURVEY
L. O. COLBERT, DIRECTOR

1. In the projection used for this chart, great circles are (within the practical limits of navigation) straight lines. Hence, the meridians, being great circles, are shown as straight lines while the parallels, not being great circles, appear as curves.

2. Straight lines connecting any two points on this chart or on a consecutive series of these charts joined together, follow closely the arcs of great circles and therefore represent the shortest and most direct courses between points in question.

3. Radio ranges, visual ranges, radio bearings and visual bearings lie in the planes of great circles, hence are represented on the chart by straight lines. Bearings are plotted using the meridian nearest the observer. When radio bearings are determined at and transmitted from radio direction finder stations they should be plotted from those positions.

Symbols printed in red on the chart.



Radio Range
Bearings are magnetic at the station

Lines of equal magnetic variation - - - - - - - -
Values for 1942

Prominent transmission line –┬––––––––┬–

◎ Army, Navy, or Marine Corps Field
(for civil aircraft use only in emergency)

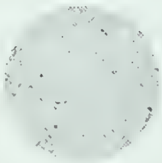
⚙ Commercial or Municipal Airport

○ 835 Civil Aeronautics Authority Intermediate Field
(slanting red numerals at field indicate altitude)

+ Marked Auxiliary Field

⊙ RS WCAU 1210 Radio Station
(with call letters and frequency)

344 • — •



Radio Marker Beacon
(with frequency and identification signal)

⋏ 540 Obstruction
(numerals indicate height above ground in feet)

⚑ Mooring Mast

L F Lighting facilities

✹ Rotating Beacon
(with flashing code beacon)

★ Flashing Beacon

✳ Flashing Code Beacon

☆ Rotating Beacon

←☆→ Rotating Beacon
(with course lights)

Fan Marker Beacon
(75 Mcg.)

Designation of Civil Airways Limits
(airway traffic controlled)

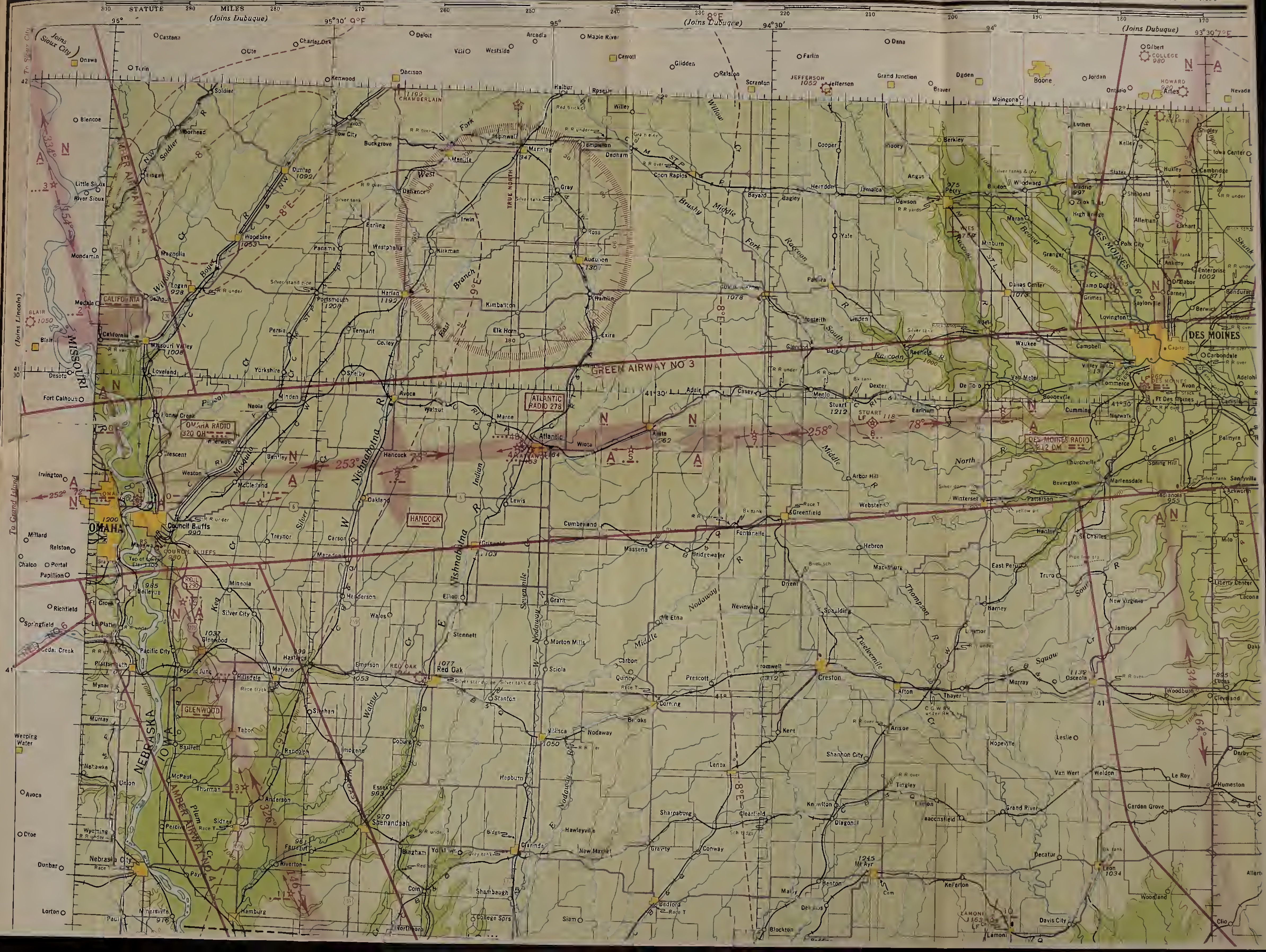
DES MOINES (U-6)

CAUTION: This chart for educational purposes only; obsolete for use in flight.

Reprinted by Courtesy of the U.S. Coast and Geodetic Survey

Portion of Des Moines Sectional Chart

C.&.G.S. Print A 1725-0



4 Great circles on the earth and straight courses on the chart, excepting meridians, intersect successive meridians at different angles, therefore such courses are slightly but constantly changing. By no method other than steering a range is it practicable to make these small changes as they occur, and thus follow a true great circle course; therefore they are permitted to accumulate and are corrected by changes in course at appropriate intervals. This results in rhumb line courses between intermediate points on the great circle. The rhumb line track departs from the great circle track a maximum amount in easterly and westerly courses, and may equal as much as 0.3 mile at the middle of a 100 mile course.

5. Rhumb line courses between any two points are measured from the meridian nearest half-way between the points in question.

6. The border scale of statute miles is uniform and may be used in measuring distances on any part of the chart.

Symbols printed in purple on the chart.

United States Highway ━━(69)━━

Highway (*prominent*) ━━━━━

Highway (*less prominent*) ─────

Symbols printed in black on the chart.

POPULATION

Over	100,000	**OMAHA**
"	25,000	**Council Bluffs**
"	5,000	Red Oak
Less than	5,000	Stuart

Railroad, one track ┼─────┼

Trolley ┼────┼────┼

Railroad, two or more tracks ╫─────╫

Forest Ranger Station ♜

Town or village ○

Oil Well Derricks (general location) ♜

Lookout Tower ⊛

Additional symbols.

Cities and large towns are indicated by yellow squares or shapes.

Gradients of elevation are indicated by varying shades of green. On the Des Moines chart the darker green represents elevations ranging between sea level and 1000 feet. The lighter green represents elevations between 1000 and 2000 feet above sea level.

student should keep this chart before him while studying problems 3, 5, 6, and 7 of this unit. The first step in studying a chart is to read carefully all notes with regard to the use of the chart, the type of projection, the sources used in compiling the chart, and other related information. The scale is approximately eight miles to the inch, so that an ordinary rule marked in eighths can be used to measure the miles between two places, although the scales printed on the individual charts are more accurate.

Laboratory Exercise 13. How far is it from (1) the Omaha airport to the Des Moines airport? (2) the Des Moines airport to the Jefferson airport?

To one who has traveled across the state of Iowa, the pale green and dark green shading confirms the fact that the country is a rolling plain and not high above sea level. In fact the legend shows that the part shaded dark green is from 0 to 1000 feet. Higher elevations are shown in shades which vary from pale brown to dark brown.

The aeronautical data are printed in red. Each class of field has a special identification symbol and beacons have symbols to enable quick identification of the various types of lights that are in use. The limits of the civil airways are marked by red lines. These limits are for the most part ten miles on either side of the center of the radio range.

These symbols can best be learned through a study of their use on the chart. For example, suppose the aviator wishes to know what the airport facilities are at Omaha, and what identifying landmarks are nearby. First he would notice that the outline of the city is shown. This means the city has a population of more than 5,000. The population legend given in the symbols on page 349 shows that the population is more than 100,000. The airport is a commercial or municipal one at the northeast edge of the city. It has a rotating beacon and an auxiliary beacon flashing the letters *OH*, in morse code. Elevation of the airport is 980 feet. The letters *LF* indicate that the field can be lighted for landing at night. A number of railroads and prominent highways enter and leave the city. There are radio towers to the north and to the south, and also prominent overpasses and underpasses. The unmistakable landmark in this case, however, is provided by the junction of the North Platte and Missouri rivers.

Laboratory Exercise 14. A study of the Des Moines Sectional chart. The approximate latitude and longitude of some of the cities are given to facilitate finding them

Equipment: Des Moines Sectional Aeronautical chart, straight edge, protractor.

Procedure: a. Examine the symbols within a ten-mile radius of Atlantic, Iowa (41° 24′ *N.* Lat. 95° *W.* Long.), and list all the information that an aviator could secure from the chart. (Remember that an explanation of the symbols is found on pages 348-349.)

b. Repeat the above exercise for Nebraska City, Nebraska; Creston, Iowa; and Red Oak, Iowa, on the Des Moines chart.

c. Repeat the above exercise for three cities found on a sectional map which includes your home.

d. What type of landing field is near Lamoni, Iowa (40° 37′ *N.* Lat. 93° 57′ *W.* Long.)?

e. Name two landmarks near Clarinda, Iowa (40° 45′ *N.* Lat. 95° 02′ *W.* Long.).

f. What river might an aviator follow from Atlantic, Iowa (41° 24′ *N.* Lat. 95° *W.* Long.) to Nebraska City (40° 41′ *N.* Lat. 95° 53′ *W.* Long.)?

g. What is the elevation of the Atlantic, Iowa, airport (41° 24′ *N.* Lat. 95° 03′ *W.* Long.)?

h. Is there a landing field near Denison, Iowa (42° 01′ *N.* Lat. 95° 21′ *W.* Long.)?

i. Is there a landing field near Red Oak, Iowa (41° 01′ *N.* Lat. 95° 13′ *W.* Long.)?

Magnetic variation. The topic of magnetism was discussed at the time the principles of the compass were explained. On the sectional and regional charts the lines of equal magnetic variation are shown by red broken lines. All variations on the Des Moines chart are to the east. East variation is subtracted from the true direction to find the magnetic compass reading. Further, the bearings printed on the radio-range courses are magnetic at the station. If it is desired to find the true bearing, the magnetic variation of the place will have to be added for places of east variation and subtracted for those of west variation. For example, the variation at Des Moines, Iowa, is about 7° *E.* The directions of the three range courses from the range station near Des Moines shown on the chart are 3°, 164°, and 258°. These directions are magnetic. The true directions can be found by adding 7° to each. They would then be 10°, 171°, and 265°. These may be verified by running a true north-south line through the point representing the station and measuring each beam. For ordinary navigation purposes the magnetic compass reading will not have to be changed to true compass reading.

Laboratory Exercise 15. *a.* What is the magnetic variation at Woodbine, Iowa (41° 44′ *N.* Lat. 95° 41′ *W.* Long.)?

b. What are the magnetic bearings of the radio-range courses from the Omaha range station? What are the true directions of the courses?

c. Find the magnetic bearings and true directions of the three range courses at the Des Moines radio-range station which are shown on the chart.

Compass roses. For convenience in measuring true directions, compass roses are printed in several places on the charts. By means of parallel rulers, courses and bearings can be measured by reference to a rose. For example, to find the bearings of Denison, Iowa (42° 01′ *N.* Lat. 95° 21′ *W.* Long.) from Atlantic, Iowa (41° 24′ *N.* Lat. 95° *W.* Long.) lay the straight edge across the two places. Then move it parallel to a line through these points and downward until it reaches the center of the compass rose. The reading at the edge of the rose is 337°.

Laboratory Exercise 16. Make use of the compass rose and straight edge to find the following bearings:

a. Perry, Iowa (41° 50′ *N.* Lat. 94° 06′ *W.* Long.) from Stuart, Iowa (41° 30′ *N.* Lat. 94° 19′ *W.* Long.).

b. Shenandoah, Iowa (40° 46′ *N.* Lat. 95° 22′ *W.* Long.) from Plattsmouth, Nebraska (41° 01′ *N.* Lat. 95° 53′ *W.* Long.).

c. Red Oak, Iowa (41° 01′ *N.* Lat. 95° 13′ *W.* Long.) from Denison, Iowa (42° 01′ *N.* Lat. 95° 21′ *W.* Long.).

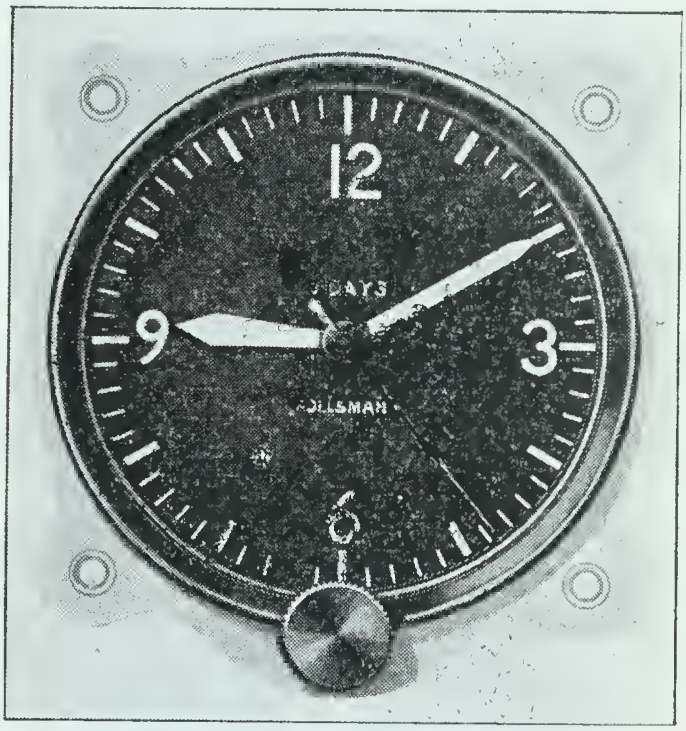
Radio information. Names, locations, identifying signals, and frequencies of weather-broadcasting stations are shown adjacent to the stations to which they apply. For aeronautical radio stations the data are shown in a rectangle; for other stations the corners of the rectangle are cut off. For example, near Omaha there is a large rectangle labeled Omaha Radio, a broadcast band of 320, call letters *OH* with the code three dashes *O* and four dots *H*. In addition, there is a small rectangle nearby with the corners cut off and the letters of the radio station KOIL with its band of 1290. This indicates that KOIL is not an aeronautical station.

Laboratory Exercise 17. *a.* What radio-station information is given near Des Moines, Iowa?

b. What information is given about the radio station at Atlantic, Iowa?

Problem 4. How are instruments used to aid air navigation?

Basic instruments. The aviator makes use of instruments of flight to help him solve problems involving distance and direction. It is not an easy matter to fly a straight, level course, high above the earth. Furthermore, man has learned that there are many things about an airplane which his senses do not tell him directly, but which he needs to know in order to fly successfully. In spite of the fact that the instrument panel of the modern long-distance airplane may contain more than 100 dials and gauges, the basic instruments for navigation may be reduced to the following: (1) clock, (2) altimeter, (3) compass, (4) airspeed indicator, and (5) drift sight.

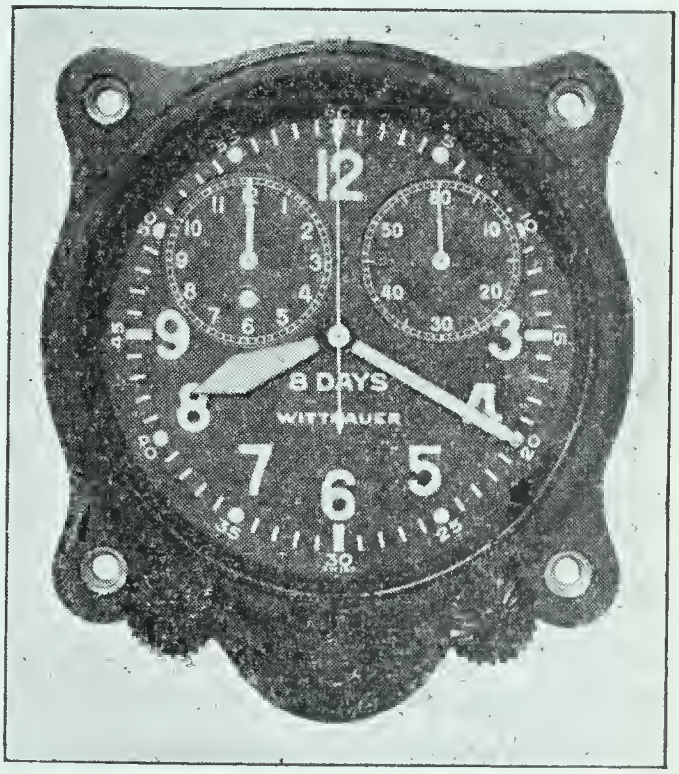


Kollsman Instrument Division Square "D" Company

Fig. 274. Standard aviation clock

The clock. The clock enables the aviator to time his flights. Any good watch is satisfactory for ordinary navigation, and a dollar watch, set to twelve o'clock at the time of take-off, can be used to show elapsed time.

Standard instrument penals are equipped with an eight-day clock. In addition to the features usually found on a clock, these have a sweep second hand. Some types have elapsed time, time out, and stop features built into them. Figures 274 and 275 illustrate various designs.



Kollsman Instrument Division Square "D" Company

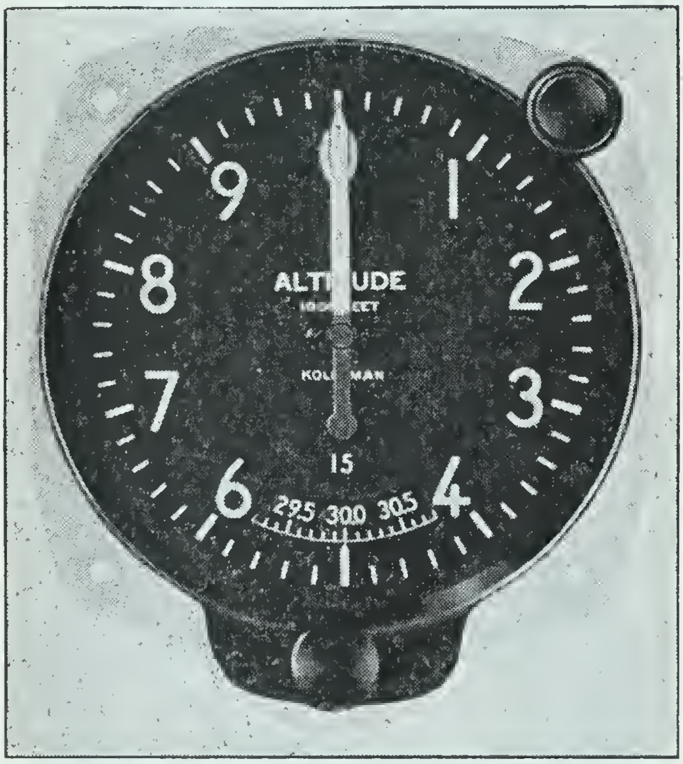
Fig. 275. Elapsed-time clock

Clocks are used for several purposes in flying. Aviators must, of course, have accurate time in order to report their position and time to control offices. Fuel consumption is calculated by the elapsed time rather than by miles as with automobiles. The time required for passing over a known distance enables the aviator to calculate his ground speed. The rate of climb and rate of turn may likewise be checked against time.

Celestial navigation by means of reference to the sun and other heavenly bodies requires the use of chronometers. A chronometer is a clock that is designed to keep unusually accurate time.

Since clocks in an airplane are subjected to great and rapid changes in temperature and pressure, they are difficult to regulate. Vibration also affects the accuracy of the timepiece.

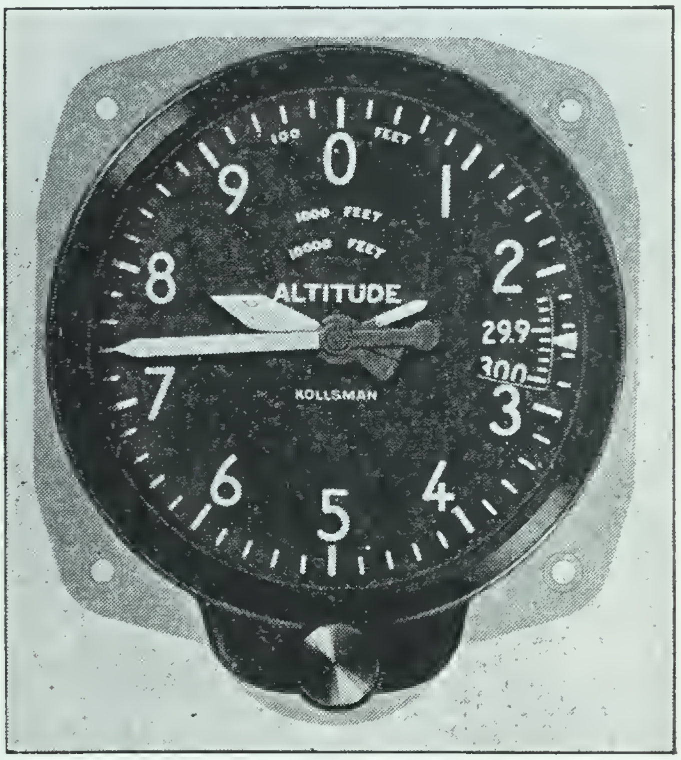
The altimeter. The altimeter indicates the height of flight. The standard air pressure at sea level is 29.92 inches of mercury. That is, the pressure of the air is sufficient to hold a column of mercury in a closed tube at a height of 29.92 inches. At higher altitudes this pressure decreases until at the summit of Pike's Peak (altitude 14,110 ft.) the standard pressure is 17.57 inches of mercury. The altimeter is a special form of the aneroid barometer and measures pressure without the use of liquid. The dial is arranged so that at sea level the reading is zero. As the pressure decreases, the reading shows the increase in altitude. The common altimeter is shown in Figure 276. It has a single pointer which indicates 10,000 feet for one revolution of the pointer. Since this instrument is graduated on a scale of 200 feet between marks, it will not register accurately changes of less than 100 feet.



Kollsman Instrument Division Square "D" Company

Fig. 276. Simple altimeter

The sensitive altimeter has been developed to give greater accuracy and more detailed readings. The pressure element consists of three circular diaphragm capsules rather than the one found in the common altimeter. These diaphragms are attached to a multiplying mechanism which will cause the hands on the dial to indicate accurately very slight changes in altitude. Figure 277 illustrates the sensitive-type altimeter which is used on military aircraft. These instruments have three pointers. The long pointer is referred to as the minute hand, the intermediate pointer as the hour hand, and the small pointer as the second hand. The minute hand makes one revolution for 1000 feet, the hour hand makes one revolution for each 10,000 feet, and the second hand indicates 100,000 feet for one revolution. The instrument is calibrated from 1000 feet below sea level to 35,000 feet above, and the second hand, therefore, will not make a complete revolution.



Kollsman Instrument Division Square "D" Company

Fig. 277. Sensitive altimeter

Elevations may be measured by two methods. The altimeter-setting method measures the altitude of the airplane above sea level. This setting enables the aviator to compare his elevation with the elevations shown on the charts and thereby keep an altitude sufficient to clear mountain peaks and other obstacles. Weather-station data are broadcast according to elevations above sea level. Similarly, airways traffic regulations are established upon elevations above sea level.

The dial of the altimeter may be rotated to read zero at any landing field. This is known as the field-elevation system. This enables the aviator to make accurate calculations for instrument landings and to determine readily the vertical distance between the airplane and the ground.

Since altimeters are very sensitive, they are subject to variations because of temperature, change in barometric pressure, lag in response to changes, and certain mechanical sources. Changes because of barometric pressure are cared for by adjusting the dial to agree with the reported barometric pressure. On one side of the dial there is a barometric scale that can be set to agree with the weather report.

Usually a few seconds must be allowed for the altimeter to register correctly after a change in altitude.

The magnetic compass. The magnetic compass indicates the direction of flight. The three characteristics of the magnet, (1) attraction, (2) polarity, and (3) orientation, were discussed under the heading *The Nature of Magnetism.* Attraction was demonstrated by showing that iron and pure nickel would move to and be picked up by the magnet. A light bar magnet or magnetized needle suspended so that it could move freely about a vertical axis took a north-south position and demonstrated the property of orientation.

The principle of the magnetic compass is based upon the fact that a magnet tends to seek a north-south position. The compass contains a magnetized steel bar balanced and supported on a pivot so that it can turn freely. The compass needle always stands with its axis on the magnetic meridian pointing north. The directions are marked on the face of the compass.

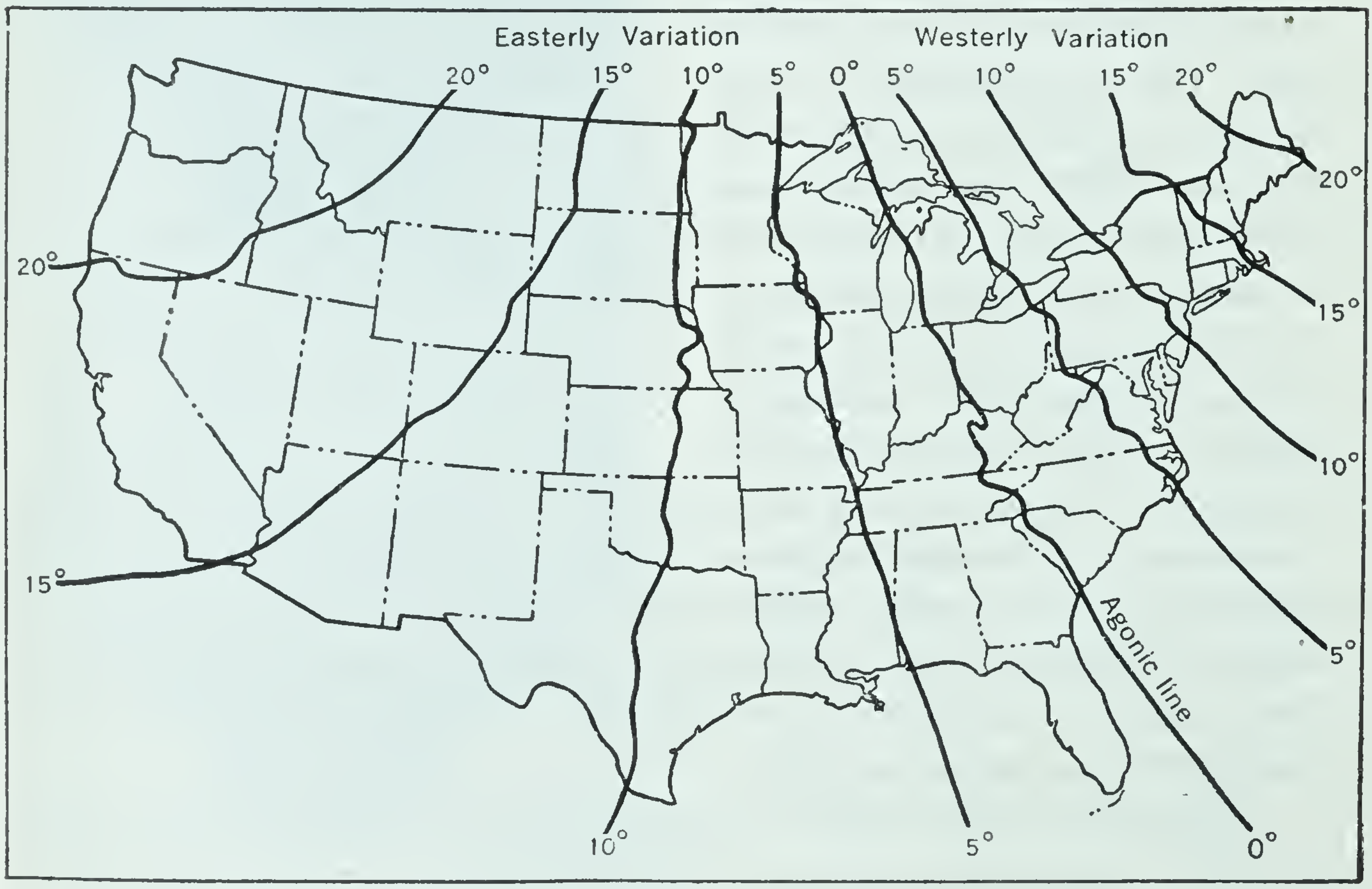
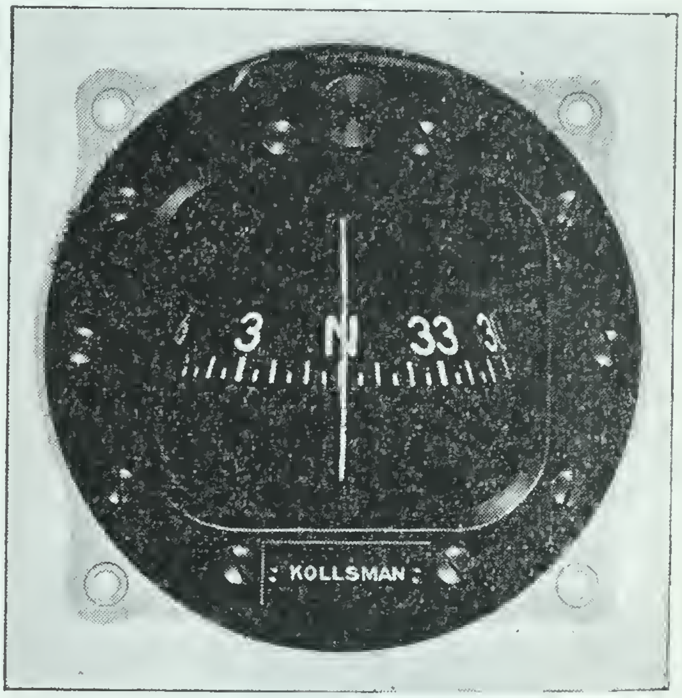


Fig. 278. Lines of magnetic variation in the United States

At most places on the earth the compass needle does not assume a true north-south position. The aviator must remember that the needle points toward the magnetic pole rather than toward the geographical pole. To complicate matters even further, the needle varies somewhat even from the magnetic pole because of local mineral deposits and other factors. The amount of variation of the compass needle away from the direction of the north pole has been charted for the whole world. On the Des Moines Sectional Chart you will find a dotted red line for every degree of variation.

This variation is also known as magnetic declination. Lines of equal variation are called *isogones*. The line of zero variation is called the *agonic line*. West of this line variation is named east, while east of it the name west is applied. Figure 278 shows isogones over the United States.



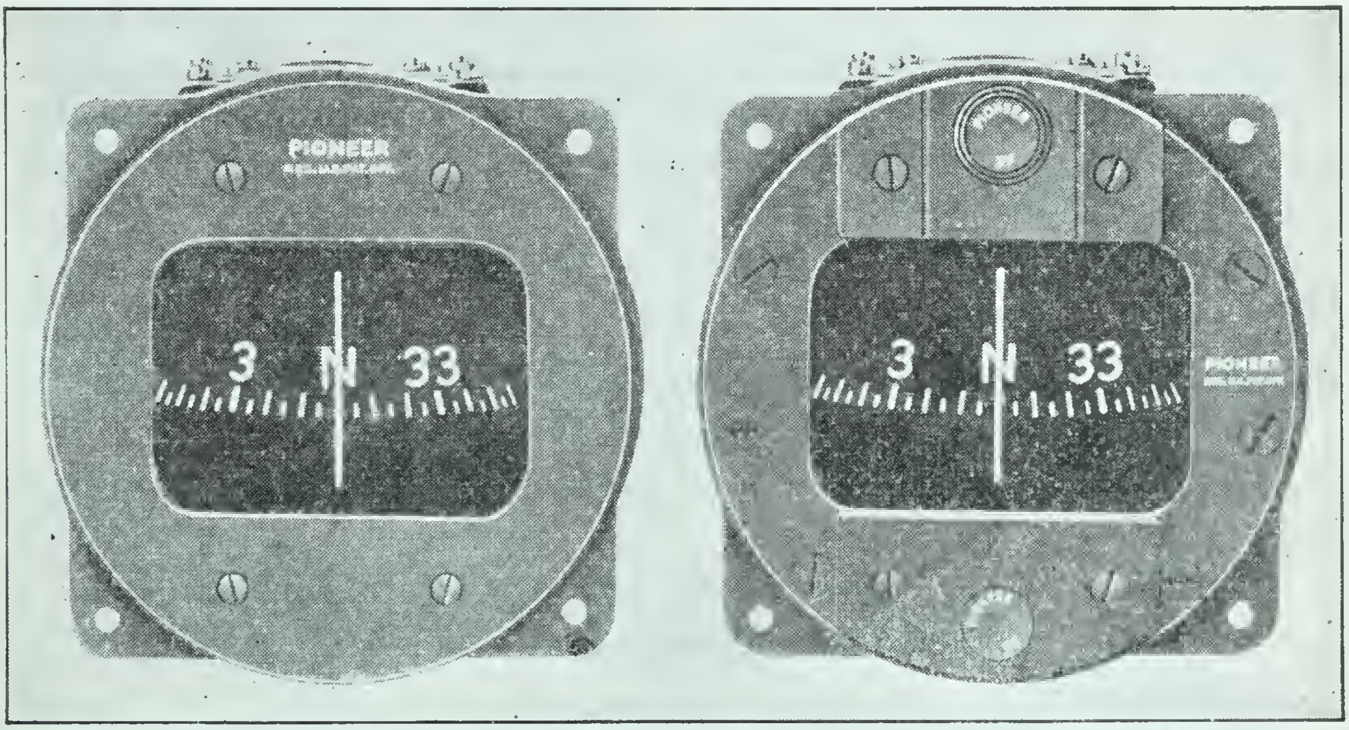
Kollsman Instrument Division Square "D" Company

Fig. 279. Aviation compass

Laboratory Exercise 18. To determine the magnitude of the compass variation in your locality.

Equipment: Long magnetized needle or compass, string, and pegs.

Procedure: Choose a spot at a distance from power lines and quantities of iron and steel. By observing the north star, lay off a true

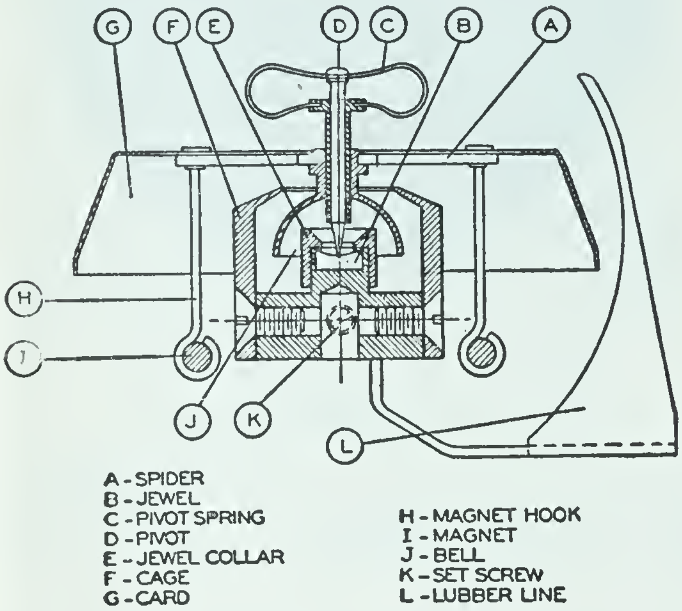


Pioneer Instrument Division Bendix Aviation Corporation

Fig. 280. Aviation compass

north-south line. To do this place a peg in the ground and sight across this peg to the north star. Place the second peg in line with the first peg and the north star. Place a long magnetized needle or compass just below the string so that the string passes through (or directly over) the center pivot of the needle. Measure the angle between the string and the needle. Compare it with the variation given in Figure 278.

Figures 279 and 280 show compasses as they appear when mounted on the instrument panel. The indicator card of the instrument-board compass is mounted on the compass needle. These cards contain two bar magnets that lie on either side of the pivot. The card is kept in place by a cage which prevents the pivot from leaving the jewel cup.



Pioneer Instrument Division Bendix Aviation Corporation

Fig. 281. Compass assembly diagram

The compass card is graduated in degrees. The cardinal points — north, east, south, and west — are indicated by the letters *N, E, S,* and *W*. The rim of the card is marked off in 50 divisions, and the thirty-degree points are marked in a clockwise direction. The unit's zero (the last zero) is omitted in every instance. Therefore, 30° appears as 3 and 60° as 6. This continues around the dial—300° is 30, and 330° is 33. Figure 281 is a diagram of the parts of the compass assembly.

The lubber line is a fixed mark on the face of the compass bowl. A line through the lubber line and the pivot of the compass card is parallel to the center line of the airplane and shows the direction of the nose of the airplane in relation to the compass.

Three forces operate to cause errors in the compass readings. These are:

1. Permanent magnetism in the steel parts of the airplane
2. Induced magnetism in the soft iron
3. Vibration

Laboratory Exercise 19. Take a small steel bar and hold it near a compass needle. What is the action of the needle?

During the process of manufacturing the airplane the steel parts acquire a certain amount of permanent magnetism. Magnetism in the steel parts remains more or less constant, but the soft iron parts of the plane are magnetized by induction from the magnetic field of the earth. The direction of the induced magnetism varies as the direction of flight is changed.

Compass deviation produced by permanent or induced magnetism is reduced to a minimum by compensation. After the compass has been mounted on the airplane, the machine is placed on a specially prepared platform or base. Then a procedure known as "swinging the ship" is carried out. The machine is headed on the magnetic north-south line and a reading taken; then it is headed to the west, then south, and finally east. Each compass has a little drawer in which compensating magnets may be placed. These tend to overcome the effects of the magnetism in the plane. After the compass has been adjusted so that the deviations are as small as possible, usually one to three degrees on any heading, a deviation card is set up and placed near the compass.

The table that follows shows a compass deviation card. To correct a bearing falling between those listed, apply the correction given for the nearest reading.

To head plane	Compass reading
0°	0°
30°	32°
60°	63°
90°	90°
120°	117°
150°	148°
180°	180°
210°	212°
240°	243°
270°	270°
300°	297°
330°	328°

Deviation Card

Errors caused by vibration and friction cannot be corrected easily, but they can be prevented to a large degree by proper construction and careful installation. Oscillation produced by vibration is controlled by damping. The damping is accomplished by filling the compass bowl with a liquid. This liquid slows down the movement of the card. A good grade of water-white kerosene is commonly used for this purpose. Increased damping may be secured by adding some clear mineral oil.

Correcting compass readings. Since a compass reading is affected by variation and deviation, it is important to be able to find the true reading from the compass reading and vice versa.

Suppose that your compass reads 40°. Your chart shows variation (the difference between the compass reading and the true geographical north) to be 10° *E*. Your deviation card shows a 2° *W* deviation for a 40° reading. How would you go about it to find the true course from the compass reading?

To correct for deviation, subtract the 2° from the compass reading. Thus 38° is the correct magnetic reading. The next step is to find the true direction. Since the variation is 10° *E*, we add the variation to the reading. Our true direction is thus found to be 48°. Could you reverse the procedure and find the compass reading from the true course?

Easterly magnetic variations and deviations are added when going *from* a compass reading to a magnetic reading or a true reading. Westerly magnetic variations and deviations are subtracted. Can you understand why, in going from a compass reading to a magnetic reading or a true reading, easterly variations and deviations are added and westerly variations and deviations are subtracted?

Midshipmen at Annapolis have long made use of jingles and phrases to help them recall how to change the various readings. A favorite phrase is: C-an D-ead M-en V-ote T-wice? The initial letters stand for compass course, deviation, magnetic course, variation, and true course.

Arranged in this way, the problem we have just solved becomes:

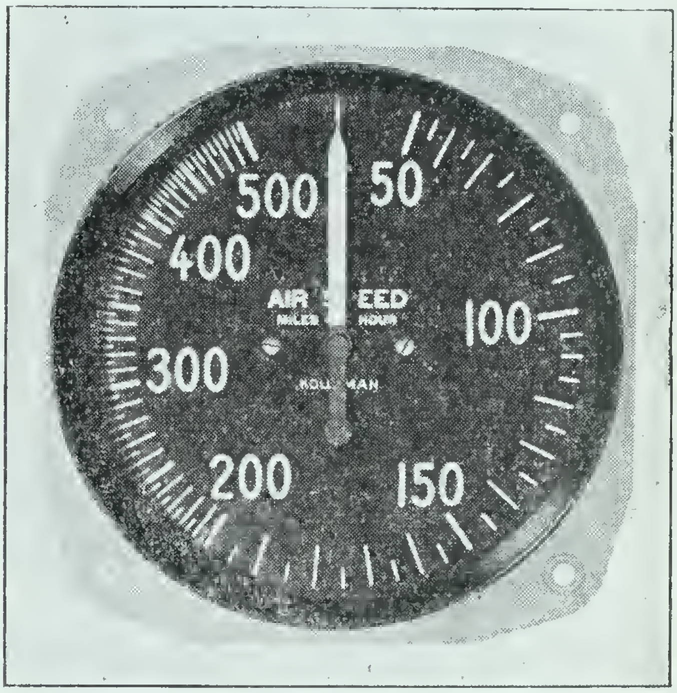
C	D	M	V	T
40°	2° *W*	?	10° *E*	?

If C, or compass reading, were our unknown, easterly variations and deviations would be subtracted, and westerly variations and deviations would be added. In short, the procedure is simply reversed.

Exercise 20. Fill in the blanks in the following chart:

C	D	M	V	T
30°	3° *W*	?	6° *E*	?
260°	5° *E*	?	12° *E*	?
90°	0°	?	10° *W*	?
?	2° *E*	?	5° *W*	300°
40°	?	?	8° *E*	50°

The airspeed indicator. The *airspeed indicator* is the speedometer of the airplane. Up to the present, no satisfactory instrument has been devised to measure the ground speed of an airplane. The airspeed indicator shows the speed at which the airplane is moving through the air, but the wind may increase or decrease the speed at which the airplane moves over the ground. The general performance of the airplane is indicated by the airspeed indicator. The forward speed of the plane is an important factor in the maintenance of flight. The indicator tells the aviator when the plane is slowing to the stalling point. The indicator also shows the attitude of flight, since the airspeed will increase if the plane heads down and will decrease on a climb. Figure 282 is an illustration of the face of an airspeed indicator.

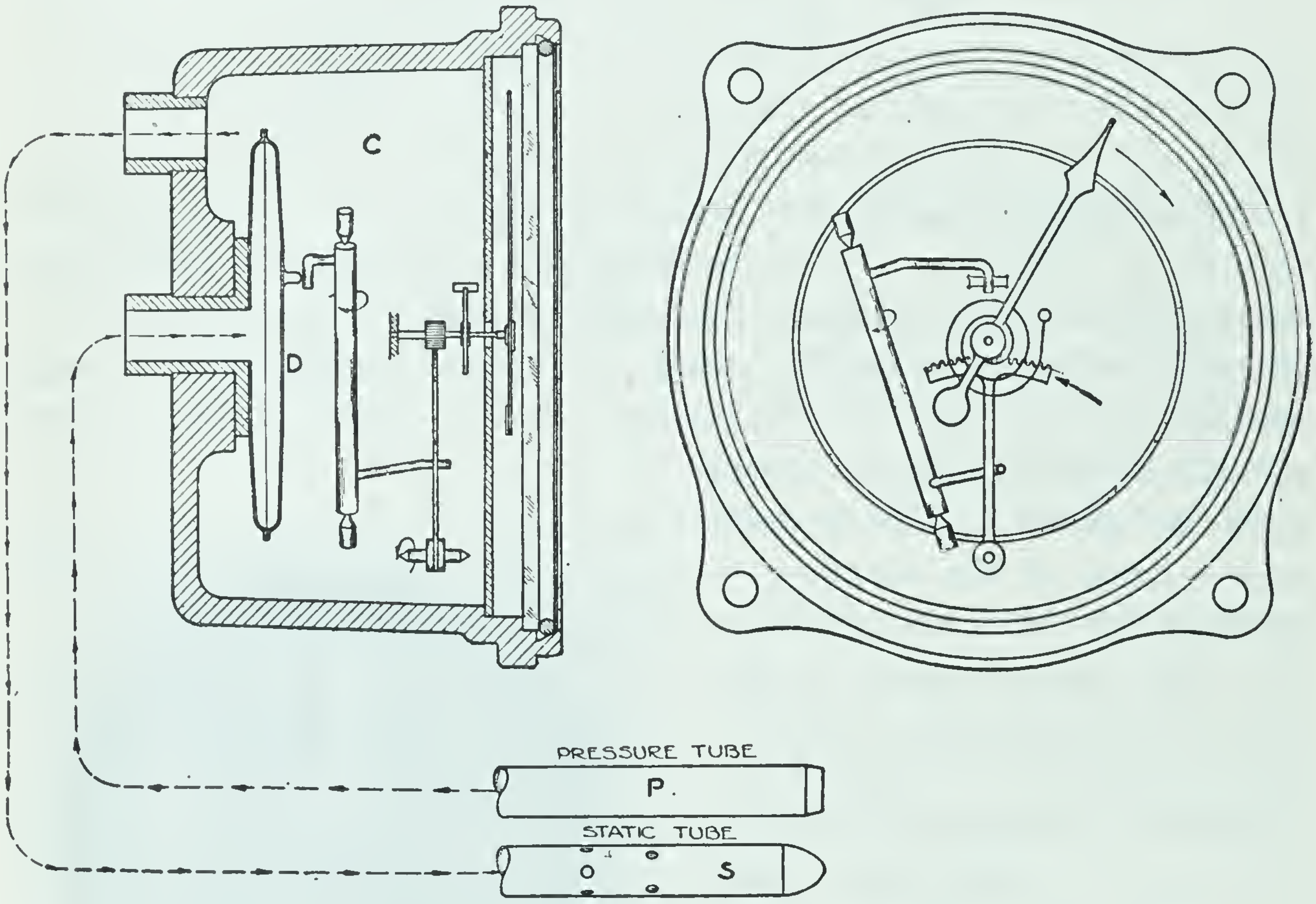


Kollsman Instrument Division Square "D" Company

Fig. 282. Standard airspeed indicator

The airspeed indicator consists of two parts, a pressure tube and an indicator. The pressure-sensitive element is a diaphragm which will move under very slight changes of air pressure. Figure 283 is a schematic view of the indicator and shows how the motion of the diaphragm is transmitted to the pointer.

The airspeed is measured by the change that takes place in the air pressure. Since it is necessary to measure both the air that is moving and the pressure of motionless air at the same point, the Pitot-static tube, a combination of two tubes, is used. The Pitot tube has an opening in the end and delivers the dynamic, or air-in-motion, pressure to the diaphragm. The static tube is closed on the end and has holes in the sides so that, even though it is filled with air, there is no air motion. It delivers to the instrument the pressure of still air.



AIR SPEED INDICATOR

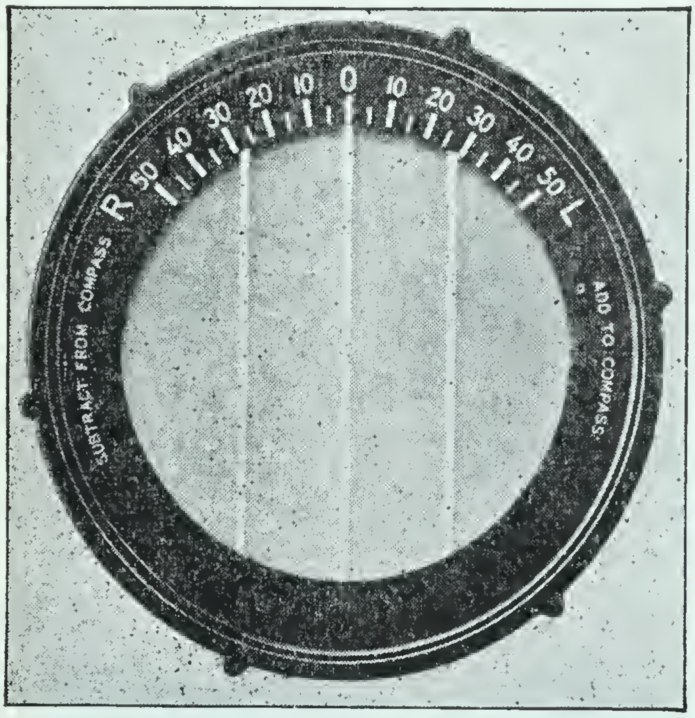
Pioneer Instrument Division Bendix Aviation Corporation

Fig. 283. Schematic view of airspeed indicator

In the winter or at high altitudes, ice has a tendency to form in these tubes. Small electric-heating elements have been built into the tubes so that when icing occurs they may be switched on and the ice melted.

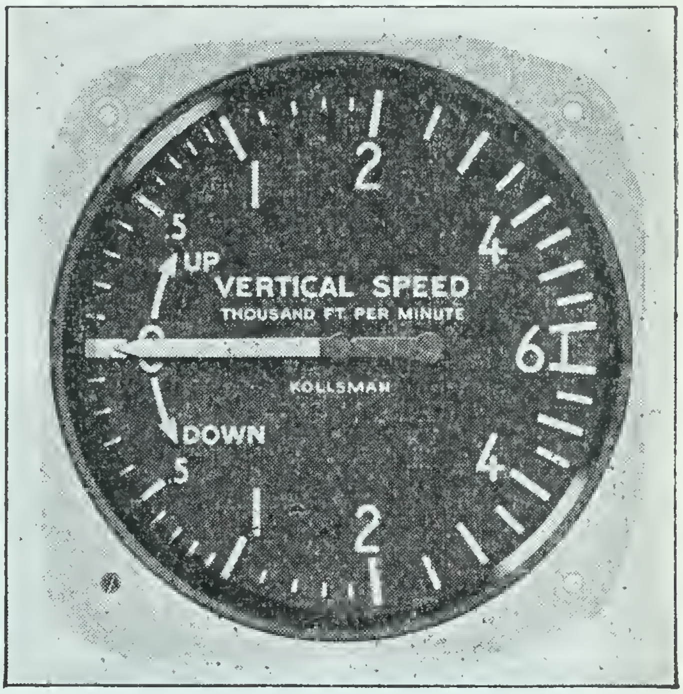
Airspeed indicators are affected by barometric pressure. In fact, the instruments are calibrated to read accurately at standard sea-level pressure. For this reason the readings must be adjusted for altitude. The normal air pressure falls as the altitude increases; therefore, the airspeed indicator will register less than the true airspeed. The correction necessary is in the neighborhood of 2 per cent for each thousand of feet above sea level. For example, at 5000 feet above sea level the true air speed is 10 per cent greater than the indicator shows. If the indicated airspeed is 150 m.p.h., the true airspeed is 165 m.p.h.

The drift sight. The *drift sight* shows the effect of the wind upon the flight of the airplane. When there is no wind the airspeed indicator (when corrected for pressure, altitude, and temperature) shows the true speed of the airplane, but the airplane is subject to the wind, and drifts in the direction in which the wind is blowing. If the wind comes from any direction except dead ahead or from the rear, the airplane will drift sidewise. The pilot must know the angle of drift in order to correct the heading of the plane. Otherwise the plane will drift off its course.



Pioneer Instrument Division Bendix Aviation Corporation

Fig. 284. Simple drift sight



Kollsman Instrument Division Square "D" Company

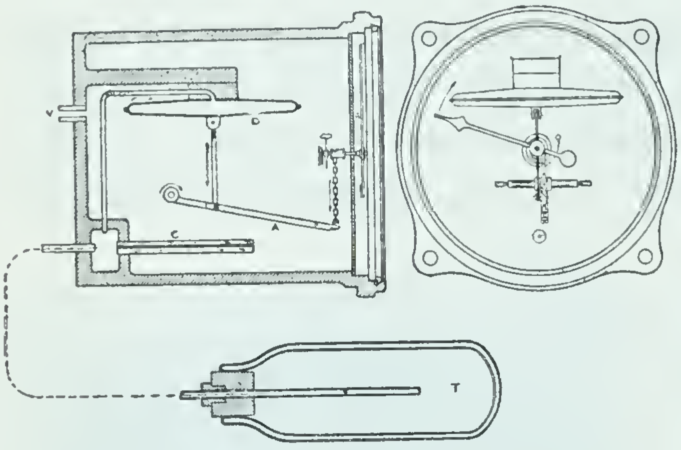
Fig. 285. Vertical-speed indicator

Drift sights have not come into wide use because frequently during bad weather the ground cannot be observed. It is, however, desirable to learn to use the drift indicator because it can often be used to make navigation more accurate.

A simple drift sight of the type shown in Figure 284 may be installed in an opening in the floor of the airplane. The line of zero drift is lined up with the longitudinal axis of the airplane.

In order to learn the angle of drift, the grid ring is rotated until the grid wires are lined up with the apparent motion of the ground. The drift angle may then be read directly from the instrument.

The wind direction and velocity can be determined by taking drift angles on more than one heading.

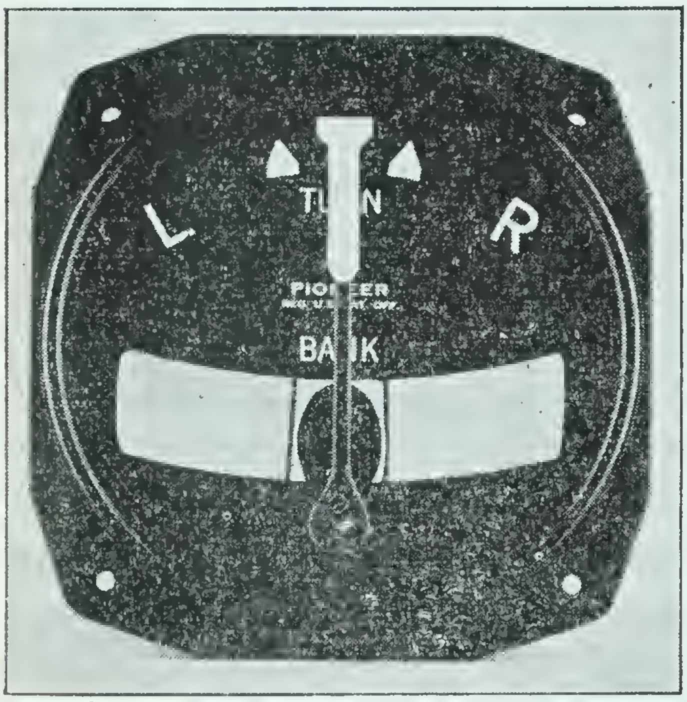


Pioneer Instrument Division Bendix Aviation Corporation

Fig. 286. Schematic diagram of vertical-speed indicator

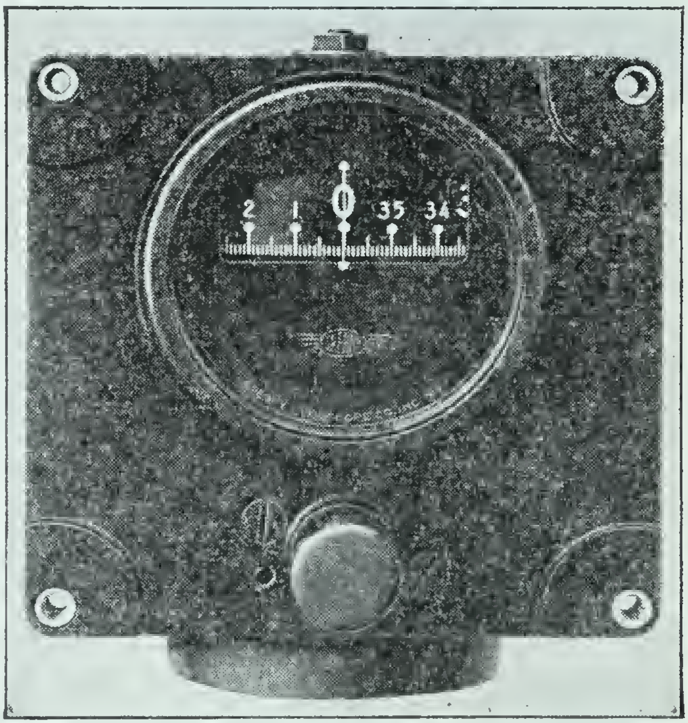
Vertical speed indicator. Other instruments are being developed to aid air navigation. Vertical speed indicators show when the airplane is flying level, as well as its rate of ascent or descent. Figures 285 and 286 illustrate the principle upon which the indicator operates. They also show the dial. The diaphragm of the instrument is arranged to show change in air pressure. On level flight the pressure remains constant; hence the pointer rests on zero.

Gyroscopic instruments. An increasingly important group of instruments is based upon the gyroscopic principle. The gyroscope, or spinning wheel, demonstrates the force of gravity in relation to the rotation of the earth.



Pioneer Instrument Division of Bendix Aviation Corporation

Fig. 287. Turn-and-bank indicator



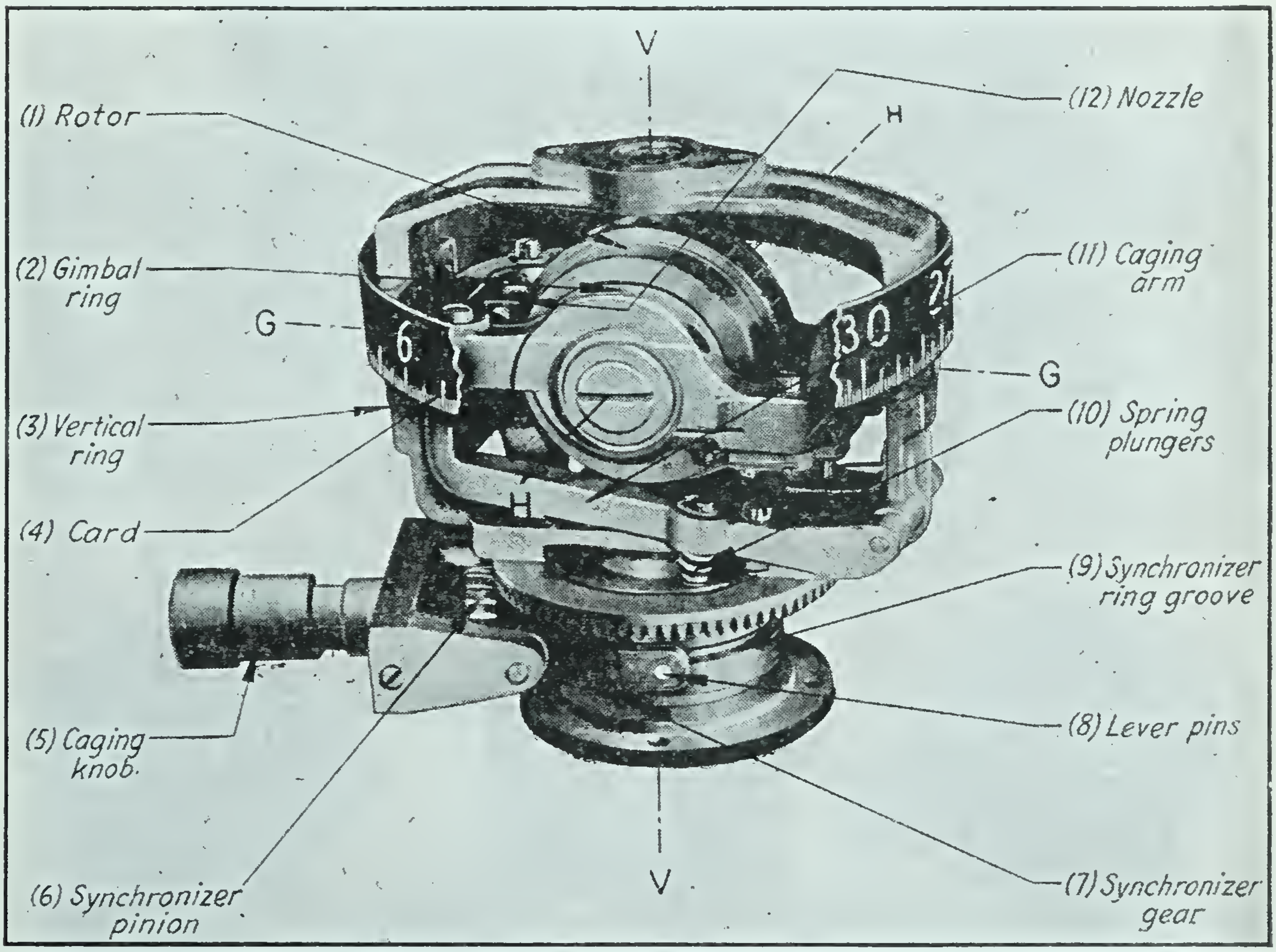
Sperry Gyroscope Company

Fig. 288. Directional gyro

Laboratory Exercise 21. Use a gyroscope top to demonstrate the various ways in which it can be used to indicate balance.

Among the gyroscopic instruments are the turn-and-bank indicator, the directional gyro, the gyromagnetic compass, the gyroscopic horizon, and the automatic pilot.

The turn-and-bank indicator illustrated in Figure 287 is really two instruments. The turn indicator shows by a movement of the hand the direction in which a turn is being made. The hand returns to the center as soon as the turn is completed. The action is controlled by a small gyroscope that is driven by the wind. The bank indicator consists of a ball free to move in a curved glass tube. The tube contains liquid that damps the movement of the ball. In level flight the ball remains in the low part of the tube (the center). If a turn is executed at the proper bank, centrifugal force and gravity combine to keep the ball in the center. If the bank is not correct, the ball will slip off center.



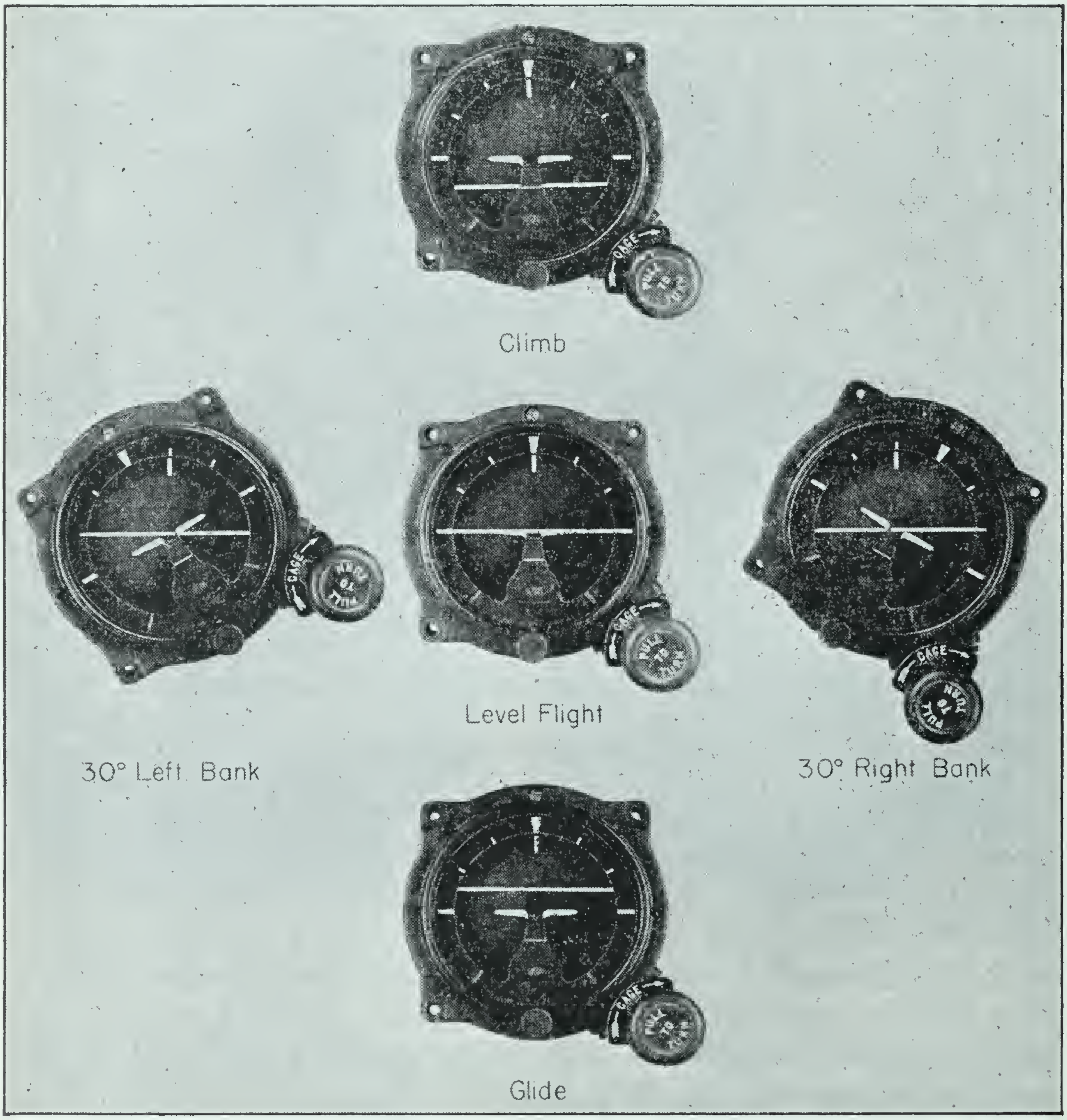
Courtesy Sperry Gyroscope Company

Fig. 289. Principal parts of directional gyro

The directional gyro is shown in Figures 288 and 289. This gyro will not seek the north pole. After a heading has been determined, the instrument can be set and will continue to point in the same direction for short periods of time.

The gyromagnetic compass combines the best features of the magnetic compass and the directional gyro. The magnetic compass gives it the north-seeking quality; whereas the gyroscope overcomes the turning error of the magnetic compass. Methods of compensating and adjusting a compass of this type need to be simplified.

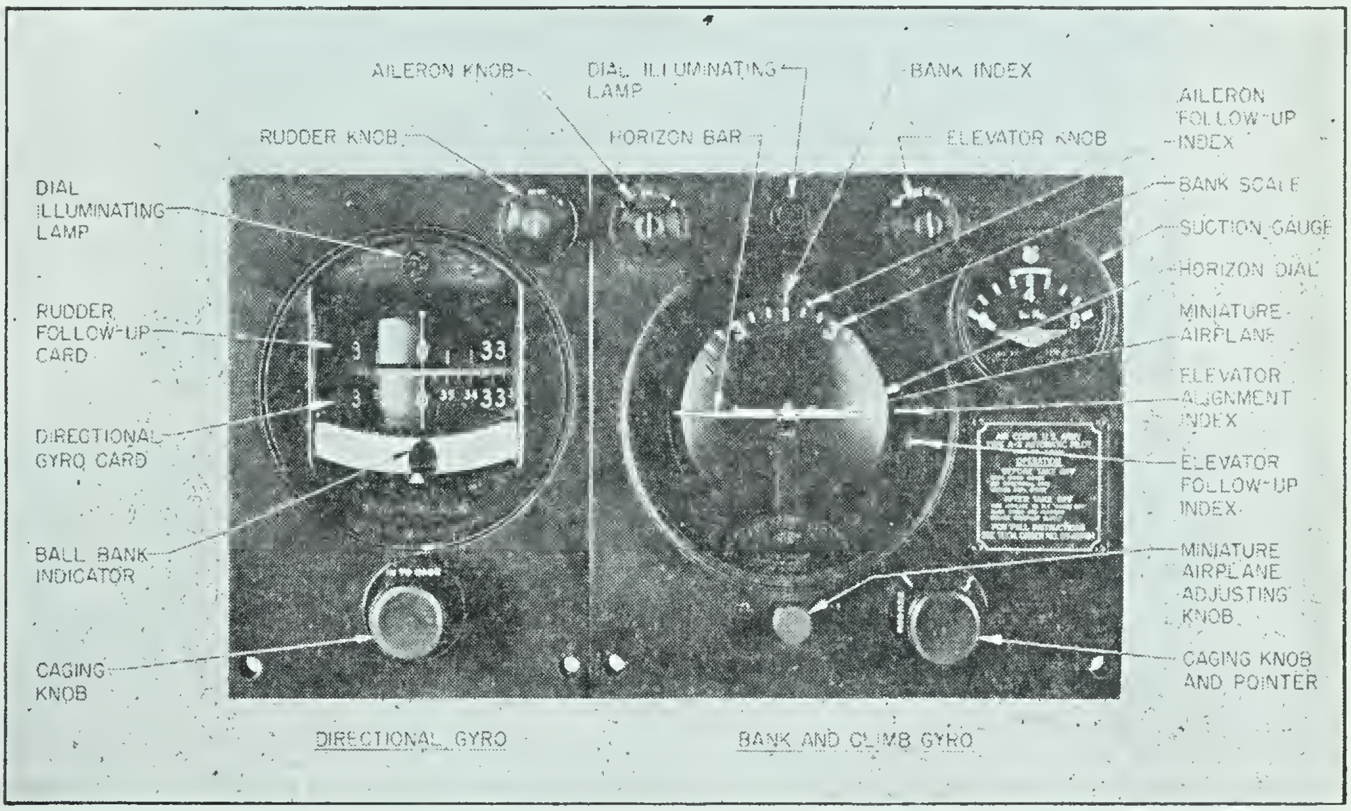
The gyroscopic horizon is commonly called the artificial horizon. Figure 290 illustrates how the instrument indicates that the airplane is in level flight, banking, gliding, or climbing.



Courtesy Sperry Gyroscope Company

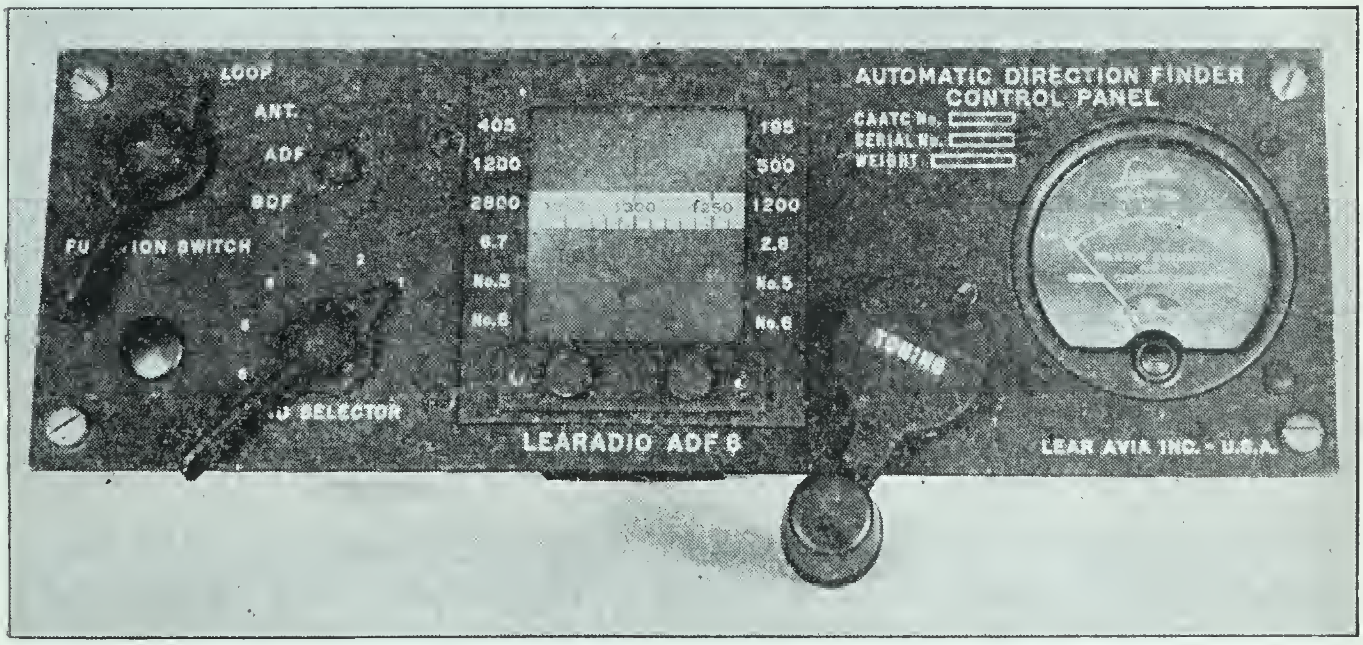
Fig. 290. Gyro horizon in various attitudes of flight

The Sperry automatic pilot can control the straight, level flight of the airplane. The instrument indicates deviation from a predetermined course and is attached to proper controls for holding the plane on course. The automatic pilot is not self-sufficient; the pilot takes the ship off the ground, sets the course, and checks at regular intervals during the flight. Figure 291 shows a view of the instrument dials of the gyro-pilot.



Courtesy Sperry Gyroscope Company

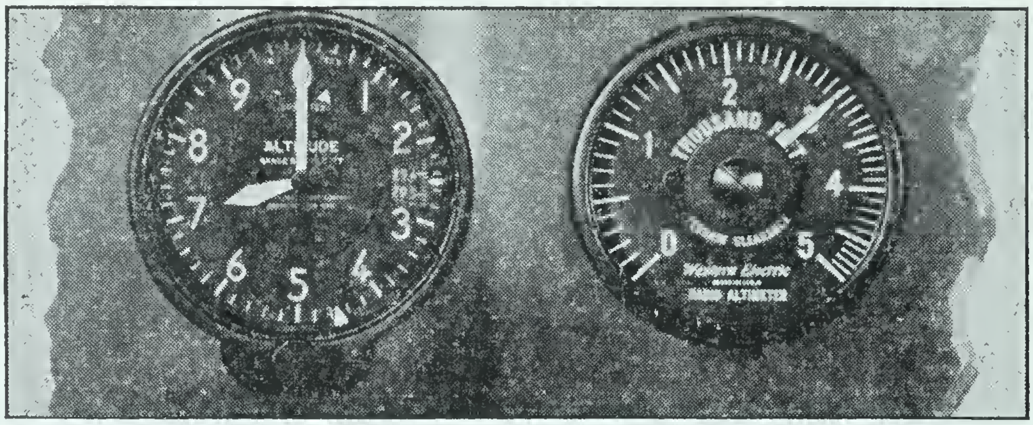
Fig. 291. Gyro-pilot unit

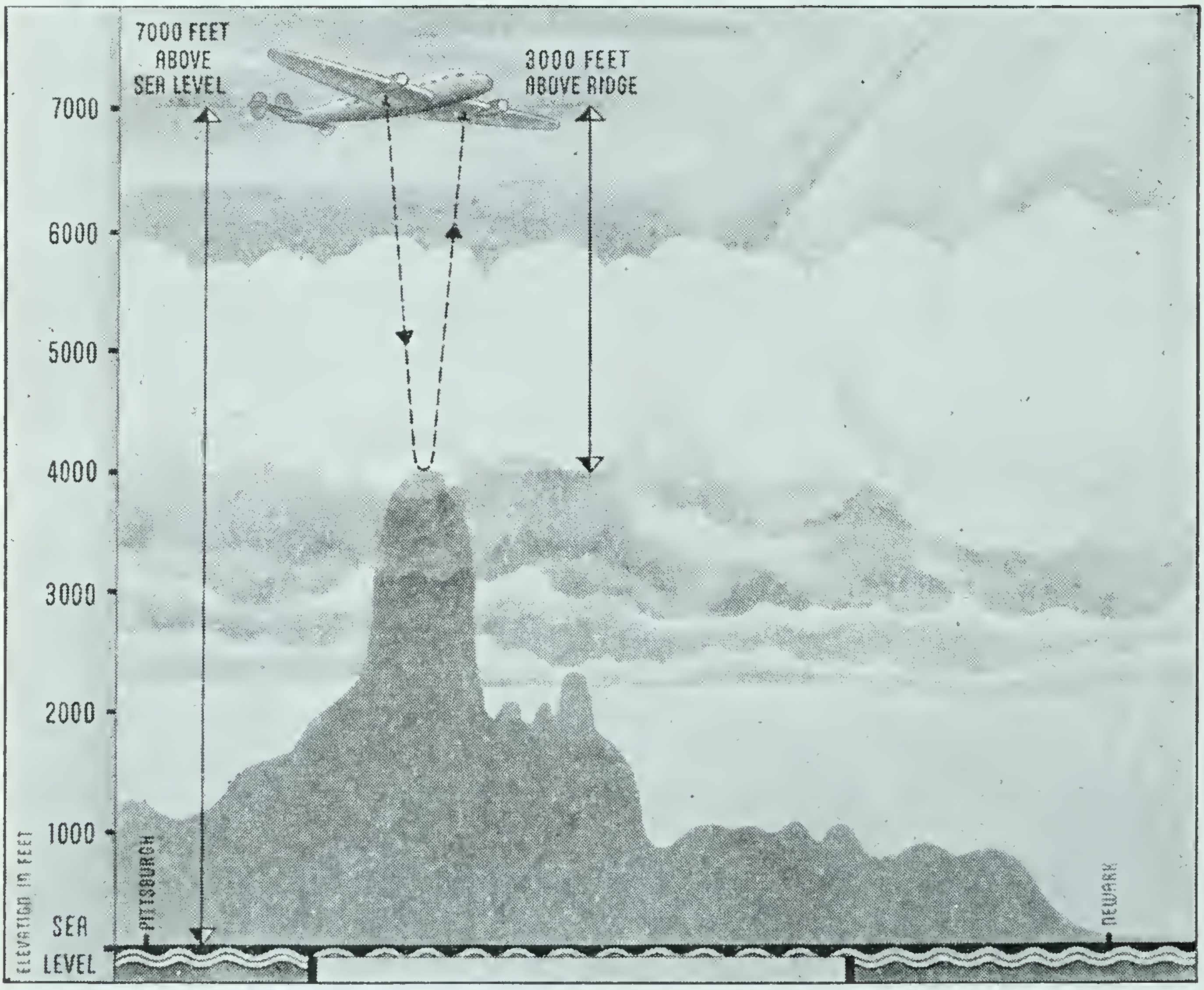


Courtesy Lear Avia Inc.

Fig. 292. Automatic direction finder

Radio instruments. Radio plays an important part in navigation. The simple *radio receiver* enables the aviator to have contact with the traffic-control tower and receive instructions, radio-range signals, and weather reports. Two-way radio gives the aviator complete facilities for communication with the ground.





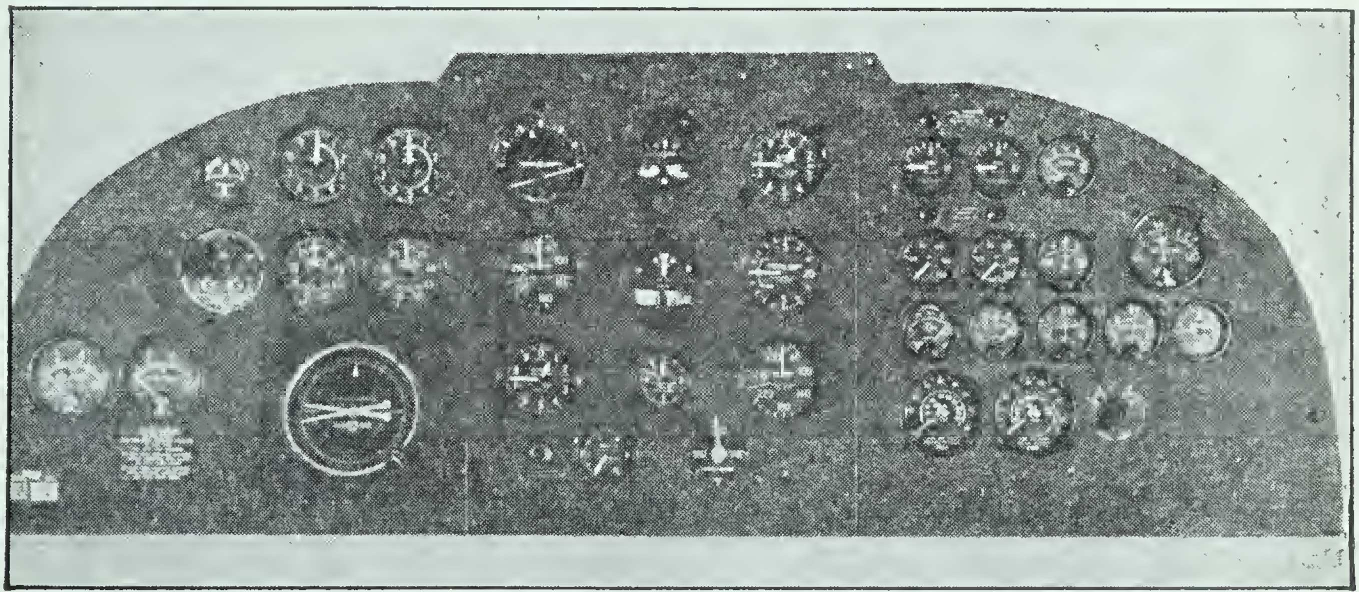
Courtesy Western Electric Company, Inc.

Fig. 293. Graphic presentation of the manner in which the radio altimeter indicates altitude

The *radio compass* makes use of the directional properties of the loop antenna which was described in the communications unit. Its chief use is to guide flight toward or away from a radio station.

The *radio direction finder* has a loop which may be rotated. By the use of this instrument the angle between the heading of the airplane and the direction to the radio station can be determined. When this information can be secured from two radio stations, the location of the plane can be plotted on the chart.

The automatic direction finder automatically indicates the direction of the station to which the set is tuned, and has scales to show the magnetic bearing and the true bearing. Figure 292 shows the panel of an automatic direction finder. The radio altimeter measures the height of the airplane above the terrain over which it is passing. Figure 293 demonstrates graphically the relation between the barometric altimeter and the radio altimeter. The dial faces show readings which a pilot might take over the highest point between Pittsburgh and Newark. The barometric altimeter at the left shows the height of the plane above sea level to be 7000 feet, while the radio altimeter shows the actual height of the plane above the terrain to be 3000 feet. In cross-country flight the altitude will show variation according to the contour of the terrain below the airplane. This instrument is not usually found in light planes.



Courtesy Mid-Continent Airlines

Fig. 294. Instrument panel for Lockheed Lodestar

The instrument panel. The *instrument panel* of even the smaller airplanes presents a substantial array of dials and switches. In general there are two groups of instruments: those that directly aid in air navigation (the flight instruments), and those that give information about the engine (engine instruments). Figure 294 is an illustration of the instrument panel of a Lockheed Lodestar. The instruments of flight are grouped near each other, and arranged so that they may be observed readily. In the interest of safety certain especially important instruments are installed in duplicate. For example, this panel has two altimeters and two airspeed indicators.

Problem 5. How does an aviator make use of visible landmarks in contact flying?

Piloting. Flying an airplane from one place to another by reference to visible landmarks, that is by visual contact with the ground, is known as *piloting.* The most important requirement for piloting is the ability to read a chart. It is also helpful to be able to use a compass.

Planning the course. The aviator plans his course before he takes off. The first step in planning is to draw a straight line on the chart from the point of departure to the destination. The next step is to examine the data on the chart to see if there are large bodies of water, mountains, or other hazardous terrain that would make it advisable not to fly a direct route. Characteristic landmarks along the route are spotted; these may be hills, railroads, highways, or other points that are easily distinguishable. Finally, the course in the air is arranged with reference to the landmarks noted.

Likewise, several safety factors must be considered. Refueling facilities should be available within the safe cruising radius of the plane with allowance for adverse wind conditions. Airports along the route should be mentally noted as places for emergency landings. Weather conditions along the route should be considered. The trip should be started early enough in the day to allow for daylight all along the way. The air-traffic rules for contact flying must be observed at all times. Under normal conditions the private pilot need not file a flight plan if he crosses airways at a height of at least 500 feet (and not more than 3500 feet) above the ground, and if he keeps at least 500 feet away from an overcast. Special care should be exercised when crossing an airway near an airport because an air transport might be descending through the overcast to change to contact flying.

Landmarks. The aviator keeps his airplane on the desired course by observing landmarks. Cultural features of the terrain constitute a distinctive class of landmarks. The pattern of roads, railroads, and other cultural features gives to each locality its distinguishing characteristics. For example, notice the city of Des Moines with its capitol, its airport, its railroads, and its highways.

The best way to determine a position is by identifying a combination of landmarks. For example, Winterset, Iowa (about 25 miles southwest of Des Moines), can be identified by means of the yellow pit east of town, a building with a silver dome toward the north part of the city, the intersection at right angles of two improved highways, and its position at the end of a railroad.

The Civil Aeronautics Administration has placed site numbers on the intermediate fields and most of the beacons. The site number is obtained by dropping the final digit of the mileage from the origin of the airway on which it is located. For example, the beacon at Stuart, Iowa, is number eight. That means it is approximately eighty miles from Omaha. These numbers are visible from the air, but in many instances the beacon numbers are not very large.

Topographic features may be of considerable help when flying a course by landmarks. Throughout the United States there are well-known landmarks, such as the Delaware Water Gap, Stone Mountain, El Capitan, and Sugarloaf Mountain. Experienced pilots select such features as points of reference in reading and interpreting charts.

It is well to plan a flight so that a continuous landmark, such as a highway, a railroad, or a river lies to one side of the route. Then, if necessary, the aviator can fly to this landmark and from it set a new course.

Flying a range. The use of a fixed range helps the aviator to fly a direct course. To do this, the aviator selects two landmarks ahead that are known to be on the course. Then he flies so as to keep the landmarks in line. Before the first of the two landmarks is reached, another more distant object is chosen, and a second range is flown. For this purpose, any well-defined landmark on the course may be used. Even a green field may serve the purpose. This procedure is known as flying a range.

It is, of course, a very simple matter to follow a railroad, a highway, or a river if one of these lies on the course.

In many cases, it will be found desirable to refer to the magnetic compass when flying a range. If a range is known to be on course, we need not be concerned with magnetic variation, compass deviation, or wind drift. Just note the compass heading and hold the course until a new range can be established. Then, if any correction is needed, it will be cared for automatically by reading the heading needed to fly the newly established range.

Listing landmarks. It may be desirable to draw up a list of landmarks and other data that can be secured from a sectional chart when a trip is being planned. The following tabulation might be drawn up for a proposed flight from Nebraska City, Nebraska, to Indianola, Iowa.

Nebraska City to Indianola, Iowa

Landmark	*Location with respect to route*	*Distance in miles*	*Flying Time*[1]	
			in hrs.	*in min.*
Sidney	½ mile to left	12	0	09
RR	pass vertically	25	0	18
Nishabotna Riv. and RR	cross both 1 mile north of Essex	31	0	23
Villisca	cross highway 1 mile north shortly after passing RR vertically	49	0	35
Cornine	2½ miles to right	62	0	47
Creston	4 miles to right (lake between course and town)	81	1	01
Highway **Y**	**Y** intersection 1 mile south of course	101	1	16
Hanley and RR	pass over RR just south of town	112	1	24
RR	pass over second RR after following it for 3 miles	118	1	28
Indianola	silver tank near center of town; race track NW of town	128	1	36

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[1] Flying time is based upon known cruising speed of 80 m.p.h. Wind information not available at time trip was planned.

Flying the course. If during the course of a flight the aviator is uncertain of his position, he should keep a constant heading until he can identify a landmark. If the heading is changed while the aviator is searching for landmarks, all sense of direction may be lost, and it becomes increasingly difficult to identify a landmark. Neither is it wise to fly low in an attempt to secure a better view of the landmarks; such a procedure reduces the range of vision, and the normal perspective is lost.

Most aviators divide the plotted route into ten- or twenty-mile intervals before taking off. The fifty- and one-hundred-mile intervals can be marked more heavily. The scale makes it easy to check the progress along the way.

Some pilots prefer to divide the route into time intervals rather than mile intervals. For example, if a plane has a cruising speed of 120 miles per hour, it will make 2 miles per minute or 20 miles in 10 minutes; the interval at 40 miles would be marked 20 minutes, and so on. The time intervals indicate the expected elapsed time at any point on the trip.

The time intervals will not hold good if the air conditions are such that the plane has a stiff head wind or tail wind. For that reason, some pilots prefer to fly a few minutes, then plot their points according to the distance they have covered.

Laboratory Exercise 22. Use Figure 295 to secure the following information:

a. Suppose that a plotted route crosses a highway about 17 miles from the airport and that the highway is passed 8 minutes after taking off, how many miles are made good each ten-minute interval for the first hour and a half?

b. A pilot flies the first 15 miles in 10 minutes. Use the graph to show the number of miles made good each ten-minute interval for the first 40 minutes.

Problem 6. How does the aviator make use of dead reckoning?

Dead reckoning. Dead reckoning is the basis of all navigation. The expression is a strange and confusing one. Perhaps it was once written *deduced* reckoning, and later shortened to *ded* reckoning, thus becoming *dead* reckoning. In principle it is the application of facts secured from charts, compass, and other instruments to deduce, or compute mathematically, the position of the airplane. It involves finding the distance and direction of one's destination,

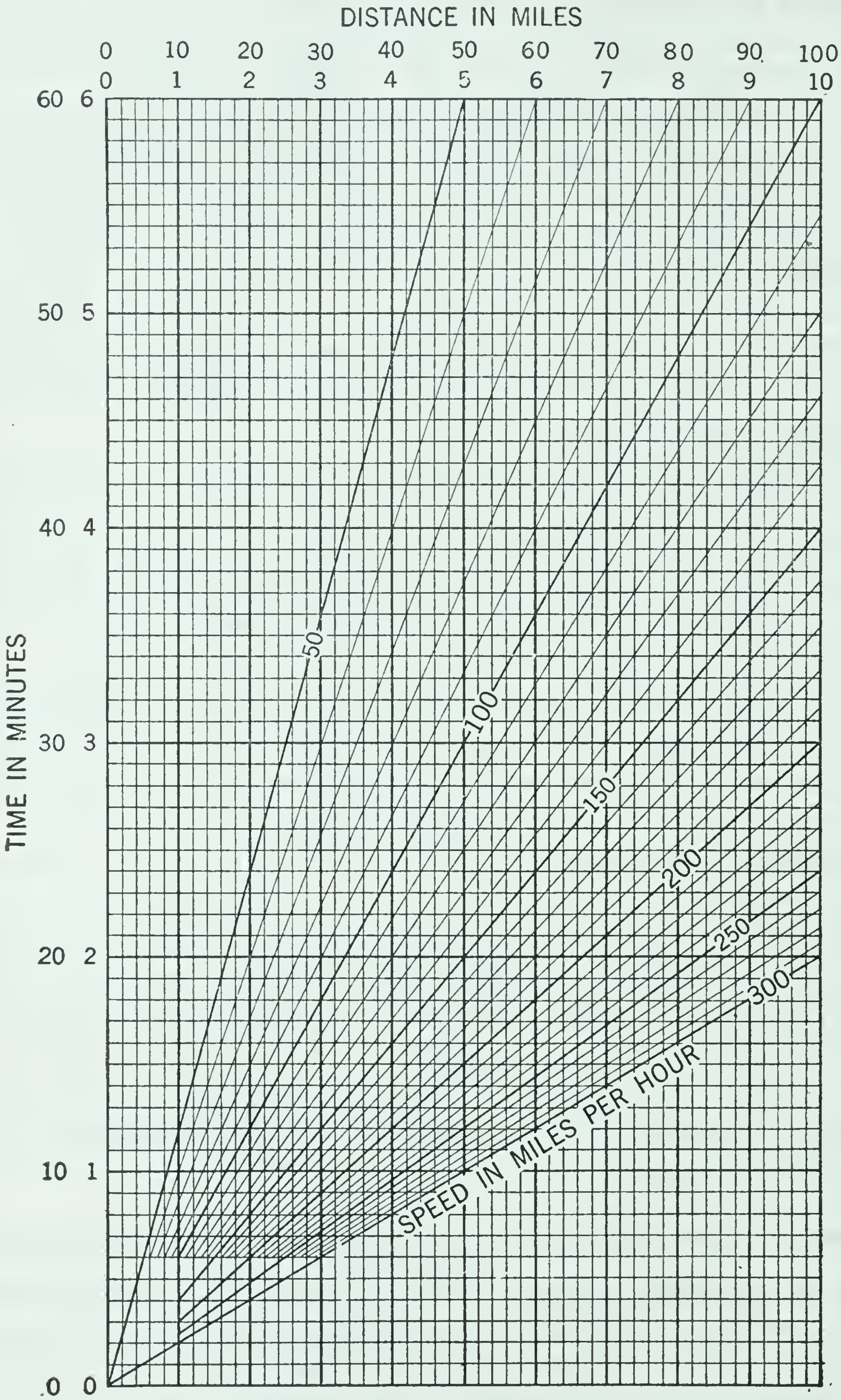


Fig. 295. Time-speed-distance graph. For distance under ten miles or time under six minutes use the inner scales. For distances over ten miles or time over six minutes use the outer scales.

determining the necessary heading, and plotting the position of the airplane.

Plotting the course. The aviator determines from the chart the distance and the course to be followed between two points. If an aviator wished to fly from Council Bluffs, Iowa, to Jefferson, Iowa, by compass, he would draw on the Des Moines Sectional Aeronautical Chart a line from the airport at Council Bluffs (41° 13′ *N.* Lat. 95° 50′ *W.* Long.) to the airport at Jefferson (42° 01′ *N.* Lat. 94° 22′ *W.* Long.). This distance measured by reference to the scale would be 94 miles. Next, he would find the direction of Jefferson from Council Bluffs. Since the line between the two points crosses three meridians, he could measure the angle formed by the intersection of a meridian and the distance line. The course is always measured at the meridian nearest to the halfway point between the two points. The direction of the line is determined by the angle it makes with north, and it is measured clockwise from the meridian. In this case the angle of direction is found to be 53°. This is known as the true course. The magnetic variation for this region is 9° *E.* The aviator would recall that east variation must be subtracted from the true course to secure the magnetic reading. Therefore, the magnetic course would be 44°. Suppose that for this course the compass deviation card in the airplane showed a correction of 2° *W.* This would give a compass course of 46°.

Laboratory Exercise 23. *Equipment:* Des Moines Sectional Aeronautical Chart, protractor, ruler or straightedge.

Procedure: a. On the sectional chart for Des Moines draw the distance line from the airport at Lamoni, Iowa, to the airport at Atlantic, Iowa. Find:

Distance in miles from Lamoni to Atlantic.
True course.
Magnetic course.
Compass course, if deviation is 1° *W.*

b. On the sectional chart for Des Moines draw the distance line from Blair Airport at Blair, Nebraska, to Jefferson Airport, Jefferson, Iowa. Find:

Distance from Blair Airport to Jefferson Airport.
True course.
Magnetic course.
Compass course, if deviation is 2° *E.*

c. On the sectional chart which includes your home, plan an airplane trip from one airport to another airport. Draw the distance line and find the true course and the magnetic course. Make an allowance for compass deviation (this could be any number from 3° *E.* to 3° *W.*) and figure the compass course.

Bearings. Another method of measuring the direction of Jefferson from Council Bluffs is known as finding the bearing of Jefferson from Council Bluffs. Figure 296 shows that the real bearing of a point *B* from a point *A* is the angle x which the line *AB* makes with the meridian that passes through the point. The bearing of *B* from *A* is the angle y which the line *BA* makes with the meridian through *B*. Angle x^1 does not equal angle x because the meridians are not parallel. If the aviator wished to fly from *A* to *B* and set his compass course by the bearing x, he would find that he would pass north of *B*. Therefore, it is customary on flights of considerable distance to measure the angle at a meridian halfway between *A* and *B* and to speak of this angle (such as angle z) as the course.

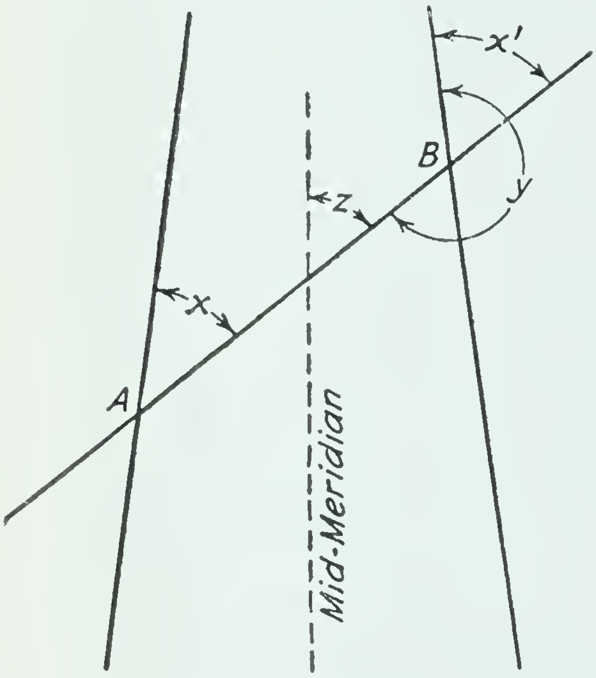


Fig. 296. Bearings

Wind drift. The aviator determines and plots the track being made good. An aviator finds that the true course from Omaha, Nebraska, to Des Moines, Iowa, as measured at the mid-meridian, is 82°. He makes the necessary compass corrections and flies toward Des Moines for an hour at an airspeed of 100 miles per hour. If the wind is not blowing, he should be able to locate landmarks that are on the course; but, if the wind is blowing, he may find that he has drifted to the right or to the left. When an airplane is flying, it is drifted by the wind. In fact, in addition to its regular speed it has a second speed equal to the rate of the wind and in the direction in which the wind is blowing. For this reason, the aviator heads his airplane at an angle that will correct the drift produced by the wind. Before taking off, he secures the weather report which gives the direction and force of the wind. The Weather Bureau always gives the direction from which the wind is blowing. Suppose in this instance the wind is blowing at the rate of 20 miles per hour from

225°. This angle is measured from the true north. A diagram of the problem would appear as in Figure 297. A straight line is drawn joining Omaha and Des Moines. A line from Omaha to *W* represents the distance that a balloon would be carried by the wind in one hour. *WP* represents the direction the plane would have to head in order to fly to Des Moines and the distance it would fly in an hour. This direction is known as the heading. The distance from Omaha to *P* is the ground speed or the track made good in an hour as a result of the combined effect of the motor and the wind. The triangle is called the wind-drift triangle. It is laid out with reference to the north-south line. Therefore, each line represents a direction from north and is drawn to scale to represent a certain distance from the point from which the airplane leaves. It is important to remember that all directions are true directions. No corrections are made for compass variation and deviation until the true heading has been found. The scale for the force of the wind, the ground speed, and the airspeed must be the same.

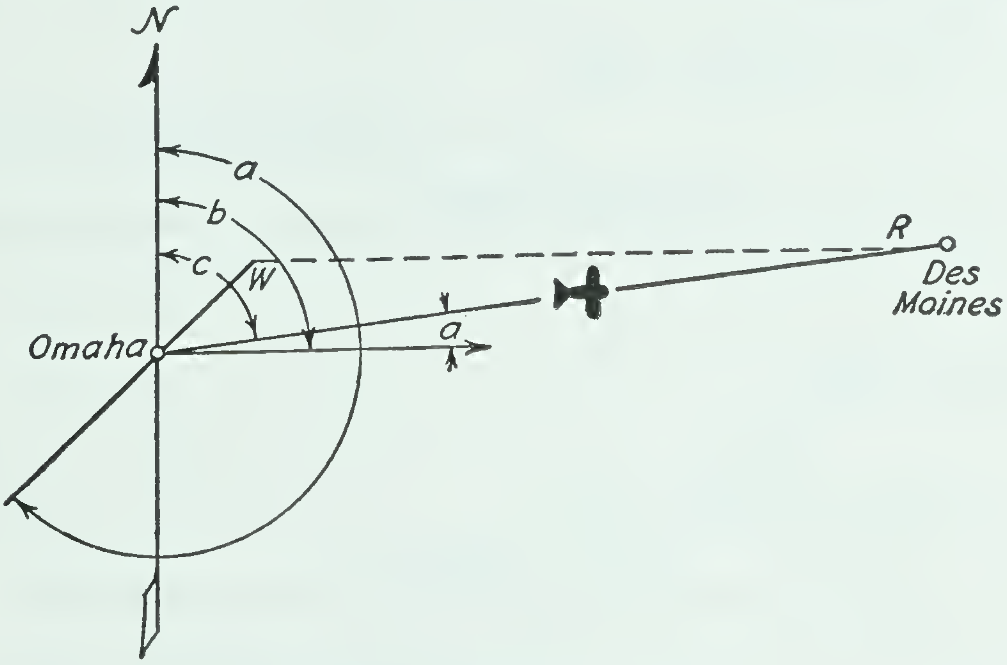


Fig. 297. Wind-drift triangle

After the heading has been determined by plotting the graph, a line can be drawn from Omaha parallel to *WP*. Angle *a* is the wind-correction angle. The heading which has been found is the true heading, and before the aviator takes off he must make corrections for variation and deviation.

The line from Omaha to *P* represents the path which the plane actually covered. It is called the track. If the track is figured for an hour, we can speak of the distance as the ground speed, that

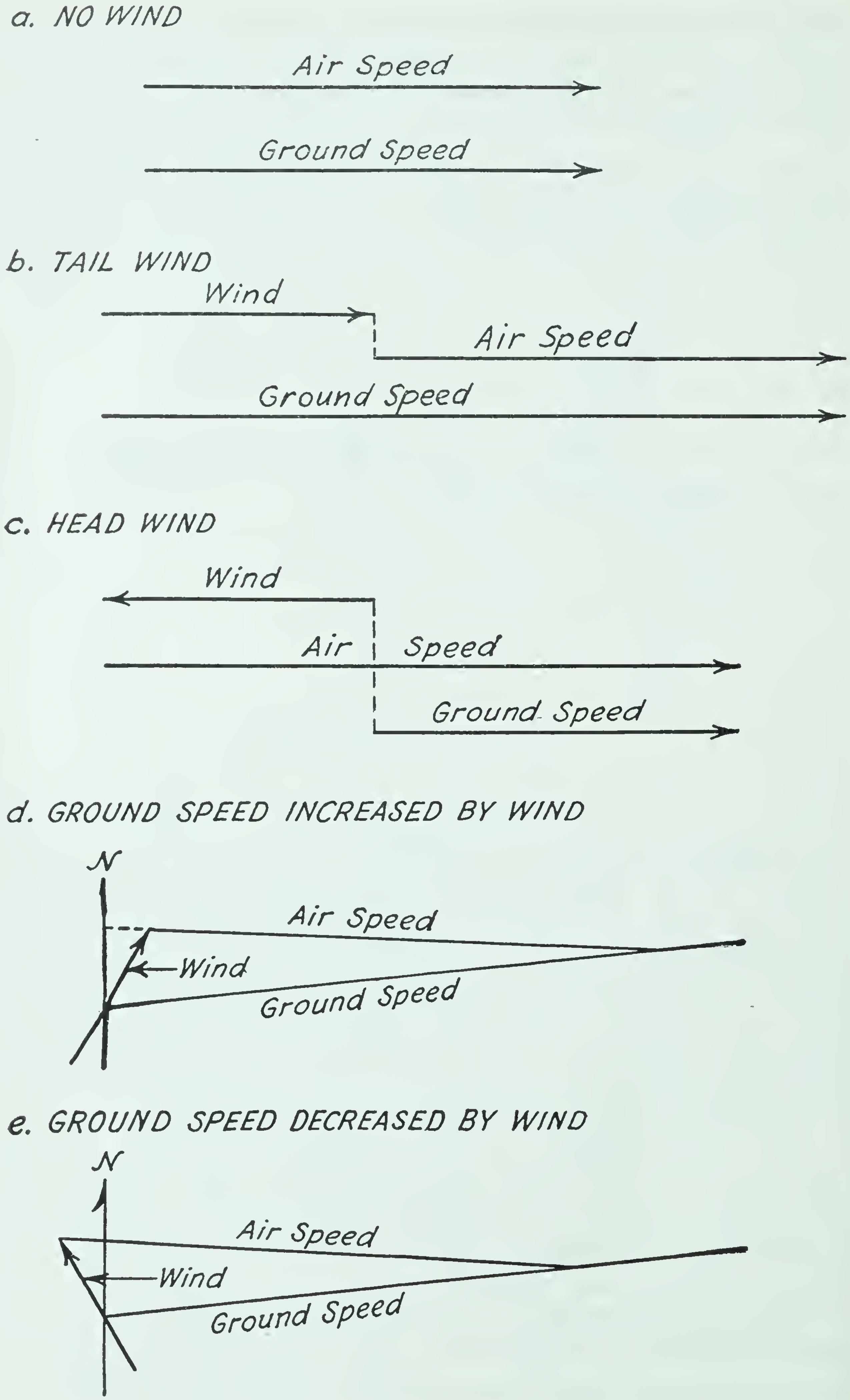


Fig. 298. The effect of wind upon ground speed

is, the speed at which the plane moves over the ground toward its destination.

The dotted line *WP* represents the speed of the plane through the air—it may be thought of as the airpath.

The relation between the air speed and ground speed may be observed in Figure 298. If the airplane is flying in still air, the airpath and the track are identical, and the ground speed will be the same as the airspeed (Fig. 298 *a*). When the wind is blowing in the same direction that the plane is flying, the ground speed will be the sum of the airspeed and the wind speed (Fig. 298 *b*). This kind of wind is called a tail wind. A head wind blows from the direction in which the plane is flying, and the ground speed is the difference between the airspeed and the speed of the wind (Fig. 298 *c*). When a wind other than a head wind or tail wind strikes the plane, the ground speed is increased or decreased according to the angle. Parts *d* and *e* of Figure 298 illustrate this principle.

Finding heading and ground speed. In air navigation, the aviator usually knows some parts of the wind-drift triangle and wishes to find the other parts. He speaks of this as solving a wind-drift triangle. For example, an aviator who wished to fly from Omaha to Des Moines knew the course and the distance from Omaha to Des Moines. He was informed of the wind force and direction, and he knew the normal airspeed of his airplane. He wanted to know the necessary heading and what his ground speed would be. He made a graph similar to the one in Figure 299.

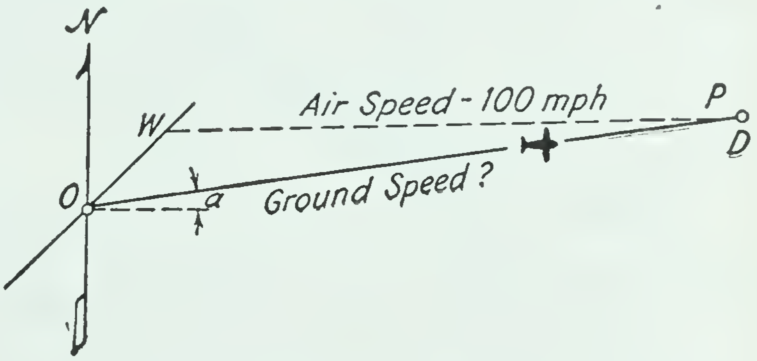


Fig. 299. Solving the wind-drift triangle

On a sheet of graph paper or notebook paper, he draws a line to represent north and labels it *ON*. At *O* (remember that *O* represents Omaha) he lays off with the protractor an angle of 82° and draws a line of indefinite length. Now he decides what scale to use. He knows that the error introduced by small inaccuracies of measurement will be kept to a minimum if he uses a much larger scale. Since the distance from Omaha to Des Moines is 117 miles, he decides to use the scale $\frac{1}{16}'' = 2$ miles. He finds that the point *D* (Des Moines) should be $3\frac{11}{16}''$ from *O*. Next he draws the line to represent the wind direction and wind force. The scale for the wind force must be the same as the scale used to draw *OD*. *W* represents the point to which a balloon would float in an hour if it were liberated at *O*. Likewise it represents the distance off track that a plane would drift in an hour. The aviator opens his dividers to that distance which represents the airspeed. Since the airspeed is 100 miles per hour and the scale must again be the same as that previously used, the dividers are opened to $3\frac{1}{8}''$. One leg of the dividers is placed at *W*, and an arc is described so that it cuts the distance at some point *P*. The line *WP* is drawn. At *O* a short-dashed line may be drawn parallel to *WP*. The direction of this line is determined by use of the protractor. It is the heading that the aviator sets in order to keep the plane on the course. The aviator finds the heading to be 100°. Angle *a* is the wind-correction angle. The aviator knows that all directions used so far are true directions and that before he takes off he must get his compass heading by making corrections for existing variation and deviation.

The final step is to measure *OP*. It represents the ground speed of the plane. In this instance the line is 112 units in length. That means that the plane has a ground speed of 112 miles per hour. Problems of this type must often be solved by an aviator.

Laboratory Exercise 24. *a.* On the Des Moines Sectional Aeronautical Chart, plan a trip from the Howard Airport, at Ames, Iowa, to Red Oak Airport, at Red Oak, Iowa. Find the distance from Howard Airport to Red Oak Airport and the true course. (Measure from airport to airport.)

Make a graph to show the ground speed, heading, and wind-correction angle if the airspeed is 100 miles per hour and the wind is blowing 20 miles per hour from 190°.

b. On the Des Moines Sectional Aeronautical Chart draw a distance line from Denison, Iowa, to Des Moines, Iowa. Find the distance from Denison to Des Moines and the true course. The wind is blowing 40 miles per hour from the north. The airspeed is 90 miles per hour. Show graphically the ground speed, heading, and wind-correction angle.

c. On the sectional chart for your region plan a trip between two airports at least 100 miles apart. Find the distance and the true course. Then construct the wind triangle if you are flying a light plane with an airspeed of 85 miles per hour and the wind is blowing 20 miles per hour from 160°.

Finding heading and airspeed. An aviator wishes to fly from Omaha, Nebraska, to Howard Airport at Ames, Iowa. The wind is blowing from due south at 30 miles per hour. It is necessary to make a ground speed of 100 miles per hour. What will be the necessary heading, and what is the airspeed that will have to be maintained for the trip? Problems of this type are probably more theoretical than practical and may not be met often in an actual situation. They are included here to suggest a second application of the wind-drift triangle.

This problem is similar to the first problem, and the solution can be obtained in a graphic manner.

On the Des Moines Sectional Aeronautical Chart a distance line is drawn between Omaha and Howard Airport at Ames. The true course is measured at the 95th meridian and found to be 66°. A north-south line is drawn on a sheet of paper and the point *O* is marked on it. (Fig. 300.) From *O* a course of 66° is drawn by use of the protractor. A suitable scale is used and the point *K* (distance from Omaha to Howard Airport) is plotted. Actually, the wind-drift triangle is based upon speeds that are maintained for one hour so the distance does not affect the solution of the problem. The distance may be greater or less than an hour's flight, but this will not affect the heading and the airspeed. Since the wind is from the south, the *wind vector,* the line representing the direction and speed of the wind, is drawn along the north line. On the distance line *OK* the hundred-mile point is marked because this is the point at which the aviator wishes to arrive after flying for 1 hour. A dashed line can now be drawn from *W* to *P*. The direction of this line is the necessary heading, and the length is the required

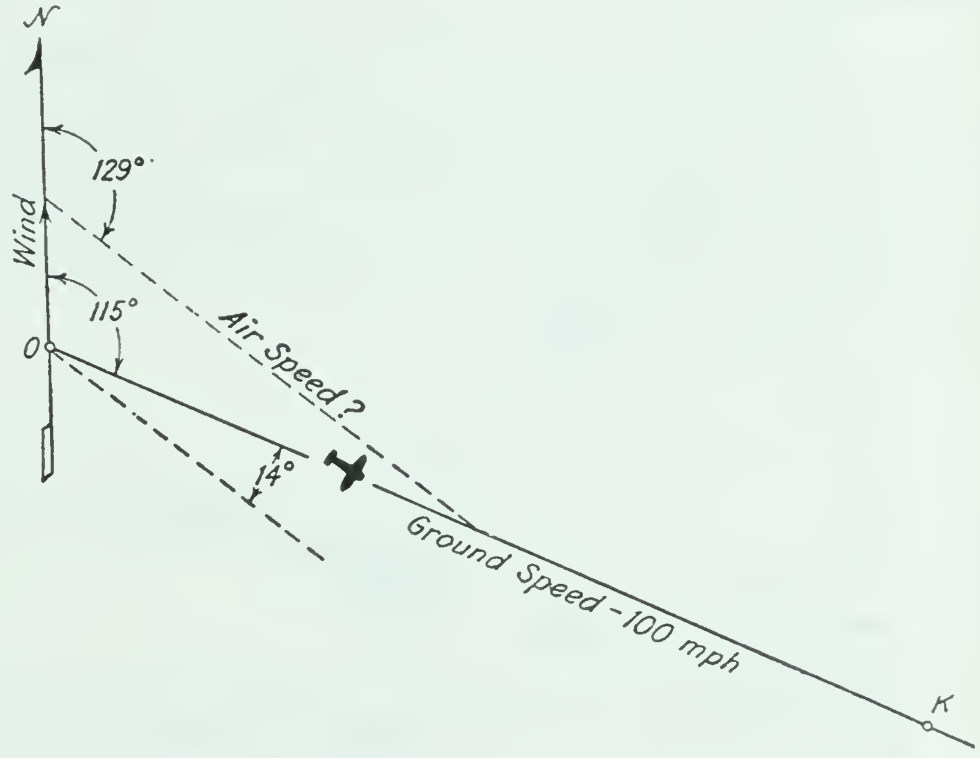


Fig. 300. Finding the airspeed graphically

airspeed. By measurement the heading, the airspeed, and the wind-correction angle may be determined.

Laboratory Exercise 25. *a.* On the Des Moines Sectional Aeronautical Chart draw the distance line from Denison Airport, Denison, Iowa, to the Lamoni Airport. Find the course and the distance. Make a scale drawing to find the required airspeed and heading if the ground speed is to be 80 miles per hour and the wind is blowing from 160° at 20 miles per hour.

b. On the Des Moines Sectional Chart draw the distance from Osceola to Omaha. Find the course and the distance between the airports. The wind is blowing 30 miles per hour from 330°. If a ground speed of 90 miles per hour is maintained, what will be the heading and the required airspeed? Solve by constructing a scale drawing.

c. Draw on a convenient sectional or regional chart the distance lines between two airports. Find the course and the distance between the airports. The Weather Bureau reports a wind of 25 miles per hour blowing from 42°. If a ground speed of 100 miles per hour is desired, what will be the necessary heading and airspeed? Solve by the graphic method.

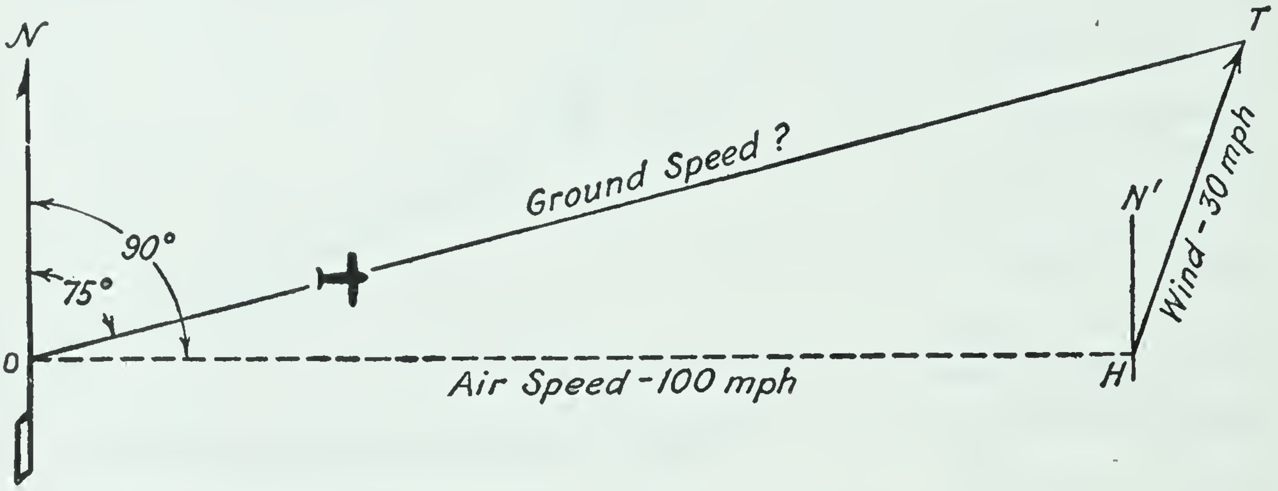


Fig. 301. Finding the ground speed and the course graphically

Finding true course and ground speed. An aviator knows the wind force, the true heading, and the airspeed. He wishes to determine the true course that he is making good and his ground speed. Suppose, for example, that the wind is blowing from 200° at 30 miles an hour, the heading is 90°, and the airspeed is 100 miles per hour. From these facts the graph in Figure 301 can be plotted and the desired information obtained.

1. Draw line *ON* to represent the north-south reference line.
2. At *O* draw *OH* 90° from *ON* and 100 units long.

3. At *H* draw *N′H* to represent another north-south line. Make sure that *N′H* is parallel to *ON*.

4. At *H* draw the wind vector from 200° and 30 units long.

5. *OT* represents the ground speed and the track being made good.

The direction of the course being made good (the track) is 75° and the ground speed is 114 miles per hour.

Laboratory Exercise 26. *a.* The airspeed is 90 miles per hour, the heading is 170°, and the wind is 20 miles an hour from 250°. Find the true course and the ground speed.

b. The airspeed is 100 miles per hour, the heading is 330°, and the wind is 20 miles an hour from 250°. Find the true course and the ground speed.

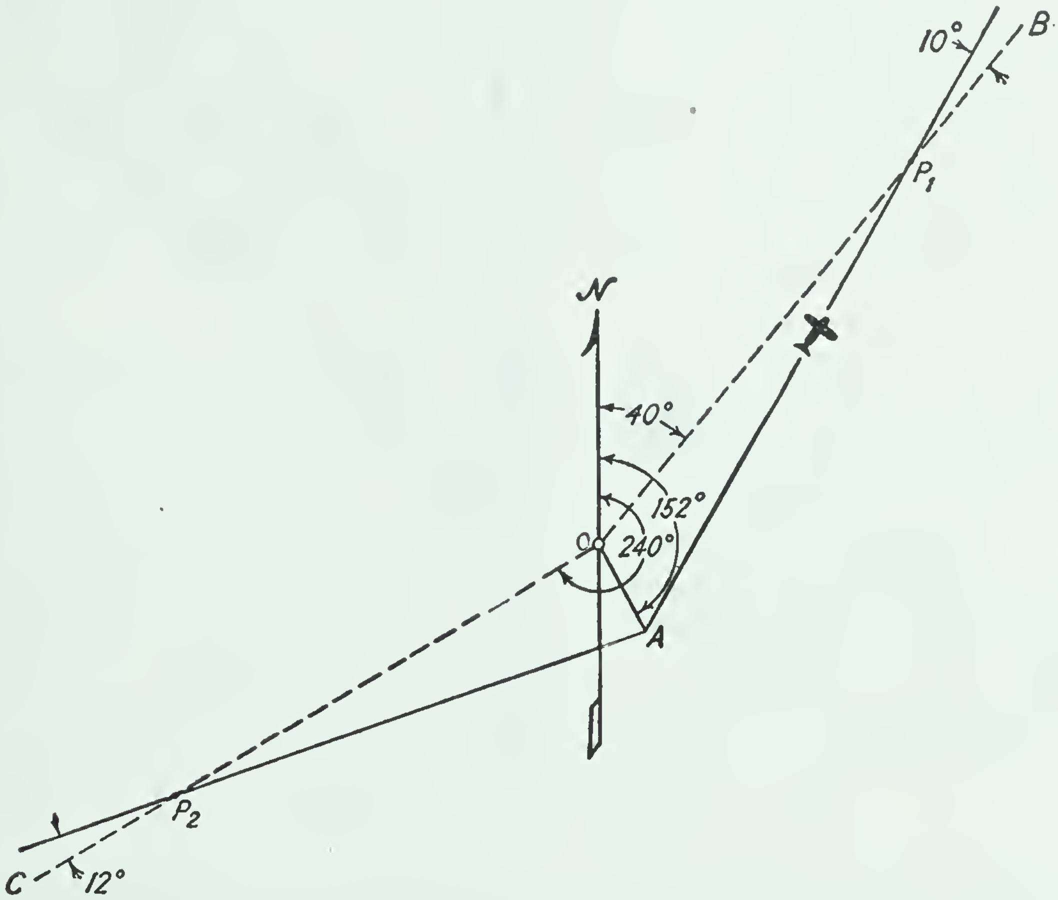


Fig. 302. Finding the wind speed graphically

c. The airspeed is 85 miles per hour, the heading is 45°, and the wind is 20 miles an hour from 270°. Determine the true course and the ground speed.

Finding wind velocity. The aviator may have reason to believe that the wind speed and direction have changed since he began flight. By recording the heading and drift angle and then flying on a new heading so that a new drift angle can be established, the aviator can plot the velocity of the wind.

For example, an aviator is flying on a heading of 40° and the drift indicator shows the drift to be 10° to the left. The aviator then heads the plane at 240° and notes a drift to the right of 12°. His airspeed is 100 miles per hour. What is the velocity of the wind?

This problem should be solved by plotting the wind triangle backward. This may appear to be an unusual method of procedure, but Figures 302 and 303 illustrate how it is done. Figure 302 shows the solution, and Figure 303 shows the complete development of the wind-drift triangles. We shall begin with Figure 302.

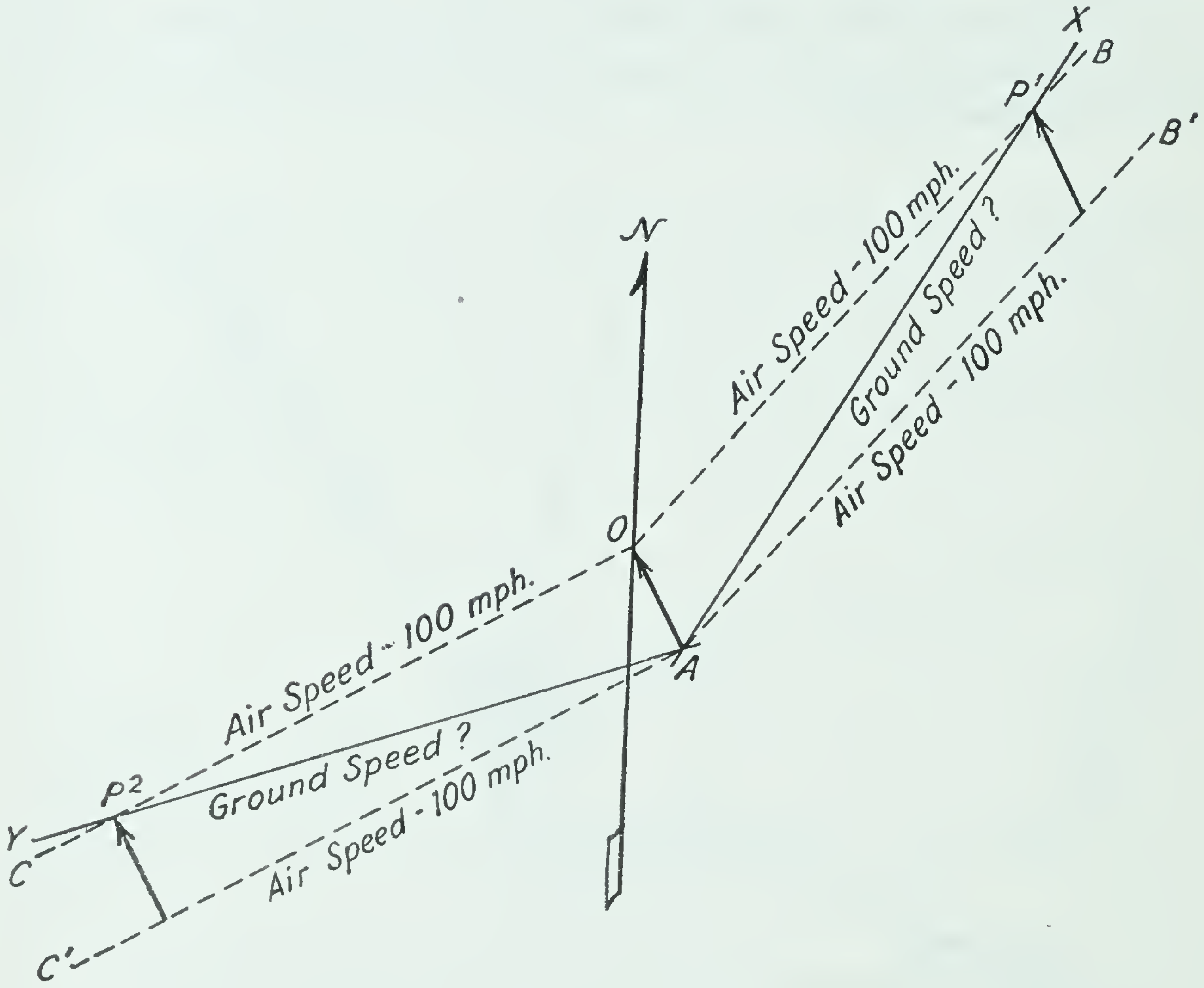


Fig. 303. The complete parallelogram for determining wind speed

1. Draw the north-south line NO.

2. From O draw OB 40° from ON and lay off OP_1 equal to the airspeed.

3. From O draw OC 240° from ON and lay off OP_2 equal to the airspeed.

4. At P_1 draw angle XP_1B 10° to the left of OP_1B and extending beyond A.

5. At P_2 draw angle CP_2Y 12° to the right of CP_2O and extended to cut line XP_1 at some point A.

6. Connect AO.

The line AO is the wind vector. It lies 152° from *ON;* therefore the wind is blowing from 152°. Since the figure is drawn to scale, AO may be measured and turns out to have a length of 22 units; therefore, the wind is blowing 22 miles per hour. Figure 303 shows the wind-drift triangles as they would usually be drawn. The plane starts from point A with a heading AB' and flies for 1 hour. AX is the actual course and P^1 is the point at which the aviator would find himself. Of course, we know that he really flies this direction only long enough to determine his drift angle. Then by the geometrical principle of similar triangles he may change his heading to AC' and fly long enough to note the other drift angle. Since the triangles have the wind side in common, they can be plotted as if the plane could leave point A and later return and start from it again. This fact clearly indicates that the direction in which the wind is blowing is from the actual track toward the heading point O.

Laboratory Exercise 27. *a.* An aviator flying on a heading of 25° observed the drift to be 10° to the right. He then headed 120° and observed a drift of 5° to the left. His airspeed on each heading was 135 miles per hour. Plot the wind direction and force.

b. An aviator is flying on a heading of 30° and notes a drift angle of 20° to the right. He heads 350° and reads a drift angle of 20° to the right. The airspeed was kept at 100 miles per hour. Show graphically the wind velocity. (The aviator thinks of velocity as being the rate of motion in a certain direction.)

c. The heading is 15°, and the drift angle is 15° to the left. The heading is changed to 60°, and the drift angle is 10° to the left. The airspeed on each heading is 85 miles per hour. Find the wind force and direction.

Radius of action. The aviator must be able to compute the radius of action of his plane. The radius of action of an airplane is the greatest distance that it can fly from an airport and return to that airport or to a second airport within its total safe flying time.

The safe flying time is the length of time that the aviator may safely fly without stopping to refuel. This time is generally computed on the basis of consumption of gasoline per hour rather than on the miles-per-gallon basis used in driving on a highway. An airplane may carry gasoline enough to fly 4 hours, but the aviator may wish to keep an hour's supply in reserve. He has a safe flying time of 3 hours and, if under normal conditions his airspeed is 85 miles per hour, he has a safe cruising range of 255 miles. This means that, if the aviator should take off from the Omaha airport, he could fly to any airport within 255 miles of Omaha. If there is a wind blowing, this range will vary. Figure 304 represents the cruising range of an airplane. A tail wind will enable the aviator to go farther; whereas a head wind will slow him down. To find the area that may be covered when there is a wind, draw a wind vector *OW*. Then draw a circle of 255 units radius with *W* as center. Lines from *O* to the circumference show how far the plane can fly in each direction.

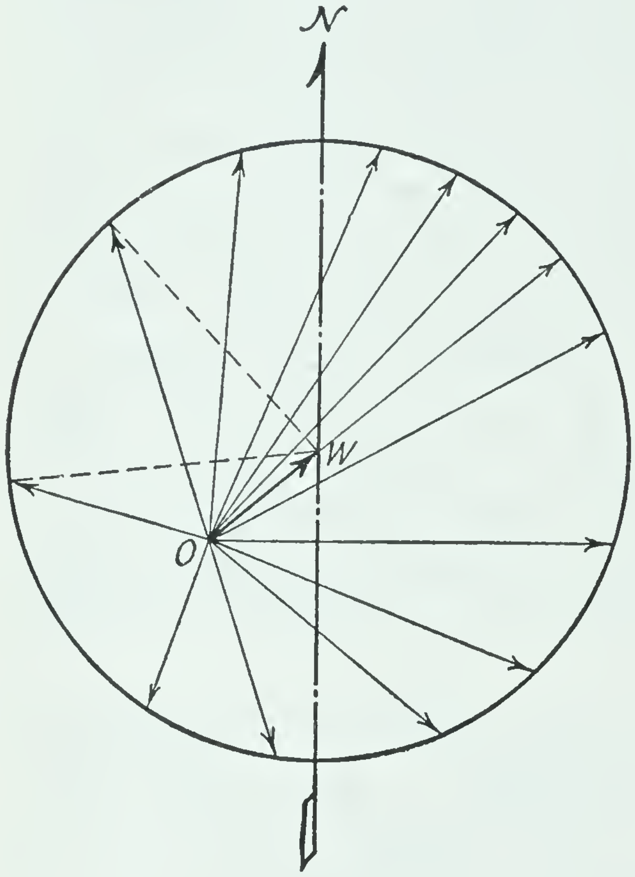


Fig. 304. Range of action

Headings and ground speeds for a round trip. An aviator wishes to fly from Omaha, Nebraska, to the airport at Lamoni, Iowa. His airspeed is 100 miles per hour. The Weather Bureau gives the wind as 25 miles per hour from 200°, and it is believed that the wind will stay the same throughout the trip. What will be the heading and ground speed for the trip out and for the trip back? What will be the total flying time?

We see at once that this problem is an important one because the aviator needs to know whether or not he can safely make the round trip in the time he has at his disposal and if the radius of action of the plane is great enough to make the flight without refueling.

Figure 305 shows that the problem is really worked in two parts and that both parts are plotted on the same drawing.

1. On the Des Moines Sectional Chart draw the distance line from the Omaha airport to the Lamoni airport.

2. Measure the distance between the airports and find the true course at the mid-meridian. (The distance is 110 miles. Course out is 114°, and the course back is 294°.)

3. On a sheet of paper draw a north-south line and at some point *O* on it lay off *OC* 114° from *N*.

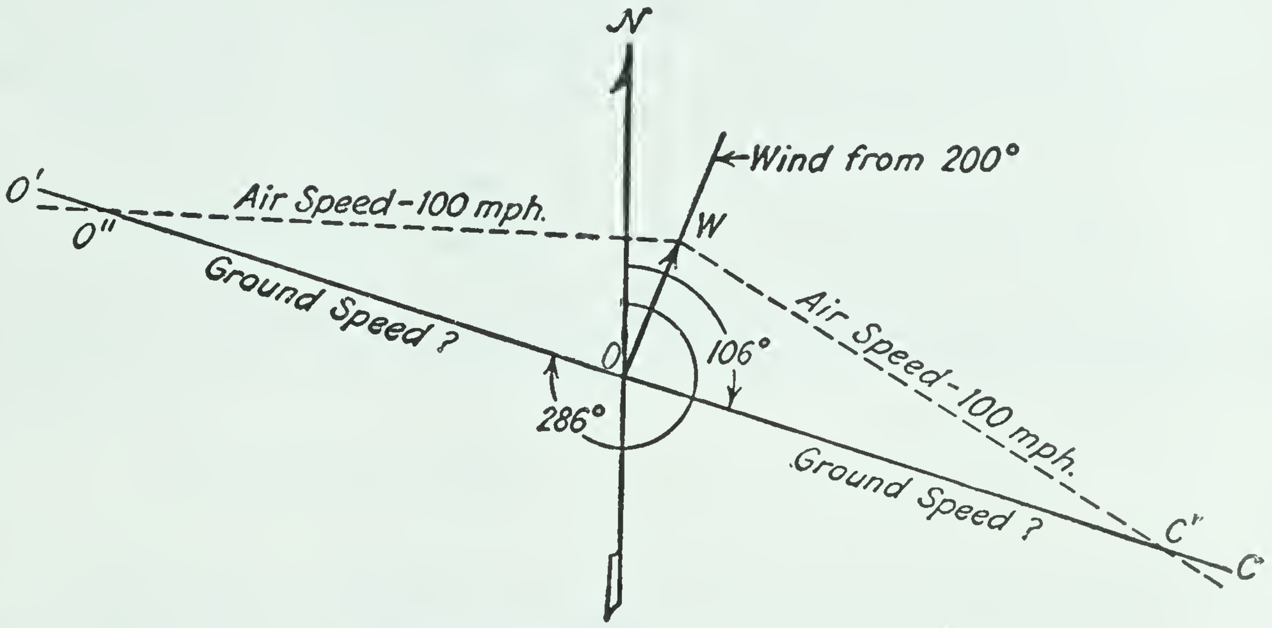


Fig. 305. Radius of action

4. Through *O* draw the wind vector from 200°. Use a convenient scale to mark the distance a free balloon would drift in one hour (25 units).

5. Set the dividers to represent 100 units on the same scale as the wind vector, and with one leg on *W*, cut *OC* at some point *C′*.

6. The triangle formed is the familiar wind-drift triangle in which the airspeed, course, and wind velocity are known. The angle that *WC′* makes with *NO* is the heading, and the distance *OC′* is the ground speed in miles per hour.

7. By measurement, the heading and the ground speed are easily determined.

8. The trip back to Omaha is known as the trip in. It is plotted on the other side of the wind-drift triangle already completed.

9. Point *O* now may be thought of as representing the Lamoni airport.

10. Lay off *OO′* from the point *O* in the direction of the true course from Lamoni to Omaha. This direction is 294°, which is 180° from the course out. By a well-known principle of geometry, we see that the line *O′C* is really a straight line.

11. The wind vector for the first part of the problem may be used for one side of the wind triangle now being constructed.

12. At W set one leg of the dividers opened 100 units and cut OO' at some point O''. The line OO'' represents the ground speed in miles per hour, and the direction of WO'' from NC'' represents the heading. The ground speed and the heading can now be measured.

The time for the round trip may be found by applying the distance formula to each part. If t_o equals the time to fly out, d equals distance, and s_o equals ground speed out, we have the formula:

$$t_o = \frac{d}{s_o} \qquad t_o = \frac{110}{98} = 1.13 \text{ hours}$$

If t_i equals the time to fly in and s_i equals the ground speed in, we have the formula:

$$t_i = \frac{d}{s_i} \qquad t_i = \frac{110}{95} = 1.16 \text{ hours}$$

Total flying time is $t_o + t_i$ or 2.29 hours (2 hours 17 minutes).

Laboratory Exercise 28. *a.* On the Des Moines Sectional Chart determine the headings, ground speeds, and time of flight for a round trip from Nebraska City, Nebraska, to Des Moines, Iowa, if the airspeed is 125 miles per hour and the wind is blowing 30 miles an hour from 300°.

b. On the Des Moines Sectional Chart find the headings, ground speeds, and time of flight for a round trip from Des Moines, Iowa, to Denison, Iowa. The airspeed is 90 miles per hour, and the wind is blowing 20 miles an hour from 45°.

c. On a convenient sectional or regional chart, plan a round trip between two airports. Assume your airspeed to be 100 miles per hour with a 25 mile wind blowing from the south (180°).

Radius of action from a fixed base. An aviator may wish to know how long and how far he can fly on a certain course and have gasoline enough left to return to his base. For example, an aviator leaves the Union airport at Lincoln, Nebraska, and flies a true course of 123°. His safe flying time is 4 hours. The normal airspeed of the plane is 85 miles per hour, and the wind is blowing from the east 25 miles per hour. At what time after the start of the flight should he turn back, and how far away from the airport will he be?

This problem can be solved by constructing a graph in the following manner:

1. Draw a north-south line and at some point *L* lay off the course *LX* 123° from *NL*. (Fig. 306.)

2. Draw the wind vector *LW*. It is to represent the wind for the 4 hours; therefore, it is 100 units long.

3. Open the dividers a distance equal to the air path for 4 hours. Put one point at *W* and describe an arc cutting *LX* at some point *Y*.

4. Draw *WY*. This is the required heading out (113°) and is the total airpath for 4 hours. *LY* would represent the distance over the ground if the trip were in only one direction. However, we want the trip to end at *L* rather than at *Y;* therefore, at some point along the air path the heading must be changed so that the airplane can go back to *L*.

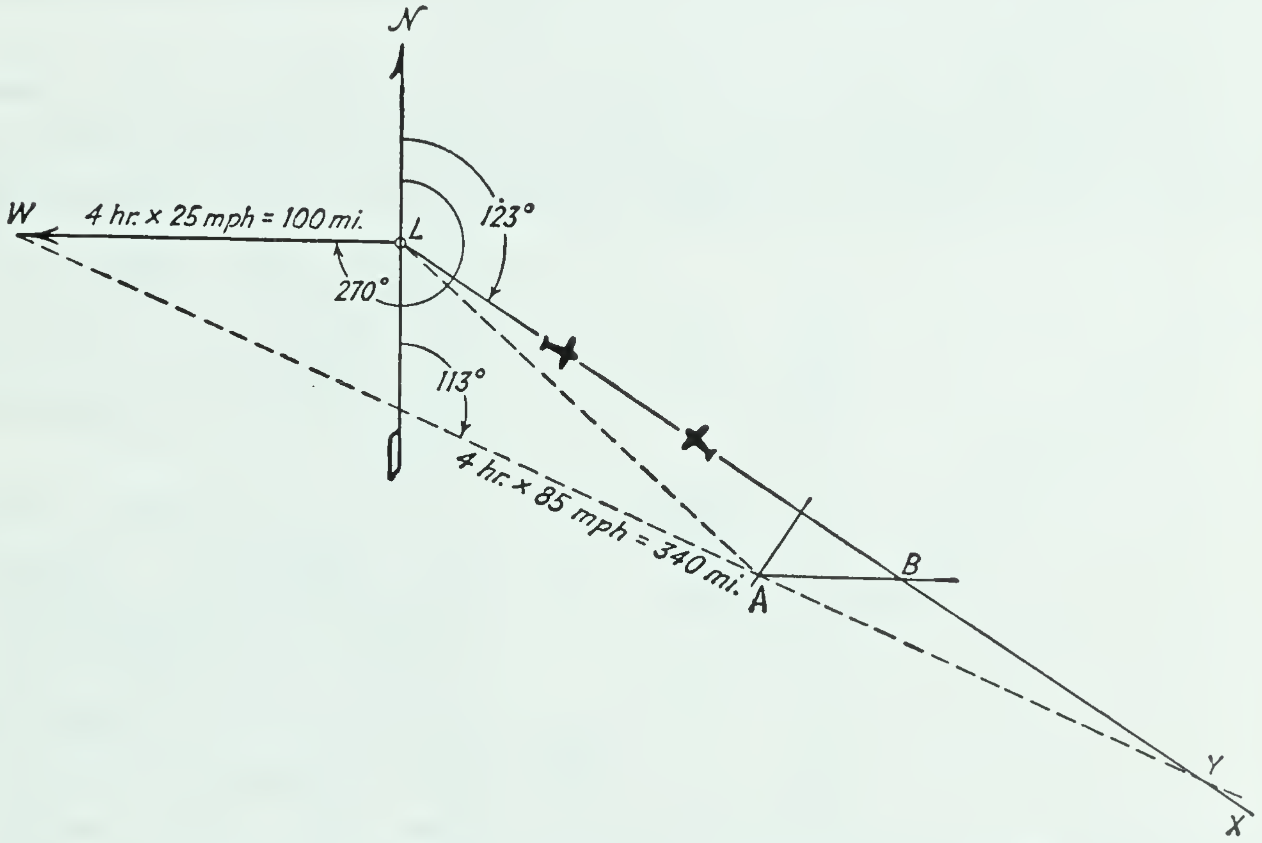


Fig. 306. Finding the radius of action from a fixed base

5. Construct the perpendicular bisector of *LY* and extend it to cut the air path *WY* at *A*.

6. Draw *LA*. A theorem in geometry states that any point on the perpendicular bisector of a line is equidistant from the extremities of the line. Therefore, *LA* = *AY*. *WA* is the length of the airpath out, and *AL* is the airpath back to *L*.

7. $\frac{WA}{85}$ gives the time the airplane can fly out. In this case it is $\frac{212.5}{85}$ or 2.5 hours.

8. Draw *AB* parallel to *WL*. *LB* is the track of the plane for the time that it is flying out. *LB* becomes the radius of action, and, while *WA* represents the airspeed path and the heading, *LB* is the track the plane actually made over the ground.

9. Triangle *LBA* is the wind triangle for the flight in. *BA* is the wind vector; *BL* is the track, and *AL* gives the heading and airspeed path. The heading for the return trip is 132°.

Laboratory Exercise 29. *a.* An airplane leaves Des Moines flying a true course of 45°. The safe flying time is 3 hours. The airspeed is 100 miles per hour, and the wind is blowing 20 miles per hour from 160°. What is the radius of action, and at what time should the plane turn back in order to reach Des Moines safely? What are the headings?

b. An aviator leaves Muscatine, Iowa, flying a true course of 210°. His safe flying time is 4 hours, and his airspeed is 90 miles per hour. The wind is from 300° at 30 miles per hour. At what time should the aviator turn back, and how far will he have flown from the airport? What are his headings?

c. An aviator leaves the Kirksville, Missouri, airport at 8 A.M. He flies a course of 345°. His safe flying time is 3½ hours, and his airspeed is 125 miles per hour. The wind is blowing 25 miles per hour from 270°. In order to return safely to Kirksville at what time must the aviator turn back and how far out will he have flown? What is the heading out? What is the heading in?

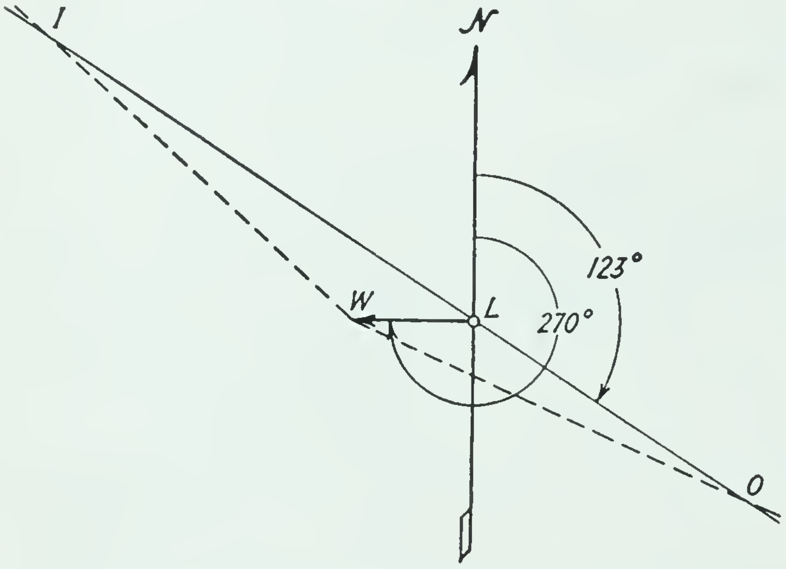


Fig. 307. Finding ground speed for radius of action

Formula for radius-of-action problems. Problems of the foregoing type can be solved by formula if the ground speeds in and out are known. These speeds can be found by a simple graph (Fig.

307). Consider, for example, the problem of the aviator who left the Union airport at Lincoln, Nebraska. Draw a north-south line, and on it lay off a 123° course. Extend the line in the direction 303° to represent the course in. Draw the wind vector for 1 hour (25 miles per hour from the east). Open the dividers equal to the airspeed path for one hour, and cut the course lines out and in. The distances cut off on the course lines represent the ground speeds out and in. (63 m.p.h. and 105 m.p.h.).

The formula we use is:

$$\text{Radius of action} = \text{Total flying time} \times \frac{(\text{ground speed out}) \times (\text{ground speed in})}{(\text{ground speed out}) + (\text{ground speed in})}$$

In the previous problem:

$$\text{Radius of action} = 4 \times \frac{63 \times 105}{63 + 105} = 157.52$$

Since the ground speed out is 63 m.p.h., the time out is 2.5 hours.

Explanation of formula. The formula for the radius of action can be derived in the following manner:

1. Let t_o equal the time out
   d_o equal the distance out
   S_o equal the ground speed out.
2. Let t_i equal the time in
   $d_i = d_o$ equal the distance in
   S_i equal the ground speed in.
3. Let T equal the total time, equal $t_o + t_i$.
4. Then

$$t_o = \frac{d_o}{S_o}, \text{ and } t_i = \frac{d_o}{S_i}$$

$$\begin{aligned} T &= t_o + t_i \\ &= \frac{d_o}{S_o} + \frac{d_o}{S_i} \\ &= \frac{d_o (S_o + S_i)}{S_o S_i} \end{aligned}$$

5. But $\frac{d_o}{T}$ = radius of action for 1 hour, $= R/A$

Therefore,

$$R/A = \frac{d_o}{\dfrac{d_o\,(S_o + S_i)}{S_o\,S_i}} = \frac{S_o\,S_i}{S_o + S_i}$$

6. The radius of action is proportional to the total flying time. The radius of action for 4 hours is 4 times the radius of action for 1 hour. We must remember, of course, that the radius of action has to be computed for each course and holds good only for that course under certain wind conditions.

7. The general formula then becomes

$$R = T\left(\frac{S_oS_i}{S_o + S_i}\right)$$

when R = radius of action in miles.
T = total time of flight in hours
S_o = ground speed out in m.p.h.
S_i = ground speed in in m.p.h.

Laboratory Exercise 30. *a.* The true course of a plane is 45°. It has a safe flying time of 5 hours and an airspeed of 125 miles per hour. The wind is blowing 30 miles per hour from 70°. Make a simple graph to find the ground speed out and in and the headings. Use the formula to find the radius of action and the time spent flying out.

b. The wind is blowing 20 miles per hour from the south. A light plane is flying a true course of 280° with an airspeed of 90 miles per hour. It has a safe flying time of three hours. Find the ground speeds and the headings. Use the formula to determine the radius of action and the time spent flying out.

c. An aviator is flying a true course of 125°. His plane has an airspeed of 100 miles per hour, and the wind is blowing 25 miles per hour from the west. His safe flying time is four hours. Find the radius of action, time out, and the headings.

Return to second base. Another type of radius of action problem is one in which the aviator takes off from an airport for a distant point and, finding conditions unfavorable, turns off his course to an airport that he can reach safely. In order to present clearly the principles involved, the problem will first be solved on a day when the wind is not blowing.

An aviator flies from Omaha on a course of 85°; his safe flying time is 4 hours. How far can he fly on this course and return to the airport at Centerville, Iowa, if his airspeed is 90 miles per hour?

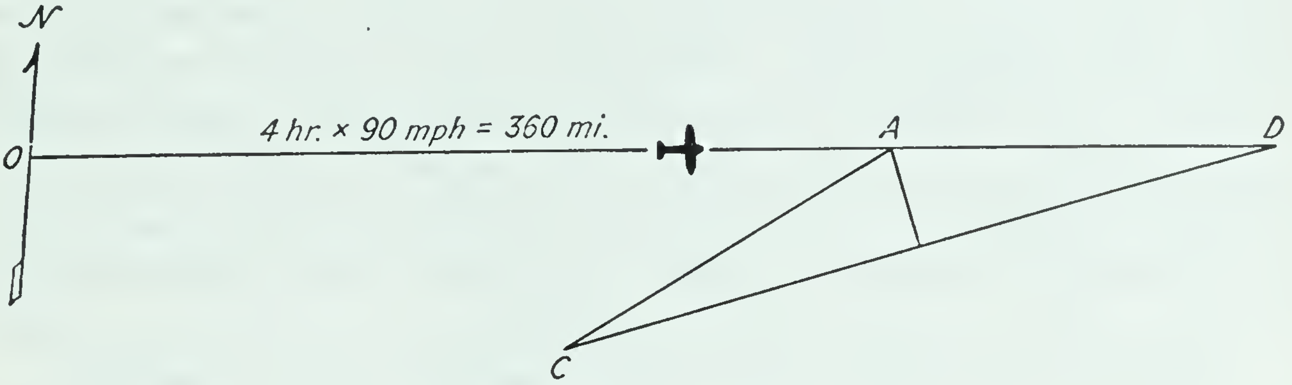


Fig. 308. Return to a second base

Figure 308 is the graphic solution of this problem. We secure the information that Centerville is 161 miles from Omaha and the course is 106°. On a north-south line select a point *O* and mark point *C* 161 units from it in the direction 106°. Next lay off an 85° course and mark *D* the point which the plane could reach in 4 hours' flight. At some point *A* along *OD* the plane must turn toward *C*. It is obvious from the graph that *AC* must equal *AD*. In order to determine *A*, draw *DC* and construct the perpendicular bisector of *DC*. Extend this bisector to cut *OD*. Point *A* is now equidistant from *C* and *D* because it lies on the perpendicular bisector of line segment *CD*.

The pilot can fly 247.5 miles toward *D* before turning to *C*. This will require 2.75 hours of flying time. Since there is no wind the heading and course are the same, and the airspeed is the ground speed.

Laboratory Exercise 31. *a*. An aviator flies from Des Moines, Iowa, on a 280° course. His airspeed is 90 miles per hour, and his safe flying time $3\frac{1}{2}$ hours. How far can he fly on this course before turning back to the Lamoni, Iowa, airport? There is no wind.

b. An airplane leaves Howard airport, at Ames, Iowa, on a 235° course. The plane has an airspeed of 110 miles per hour and a safe flying time of 5 hours. At what time after the start of the flight must the aviator head for the Des Moines airport and how far will he have flown on his course? The day is calm.

c. Plan a flight in some direction from an airport which you locate on a convenient chart. Select a second base for your return. If your safe time of flight is 4 hours and your airspeed is 95 miles per hour, at what time after start of flight will you have to turn off your course in order to reach the alternate base? How far can you fly on your selected course? Consider the day to be calm.

Return to a second airport with wind blowing. If the aviator wishes to go to a second airport and the wind is blowing, he must make proper allowance for it. Suppose in the example we have just discussed (Fig. 308) that the wind was blowing 25 miles per hour from 200°. How would this affect the radius of action? We see at once that the track and the heading will no longer be the same, that the distance the plane can follow the course will be different, and that the time of turning will be different.

Figure 309 provides the solution for this type of problem.

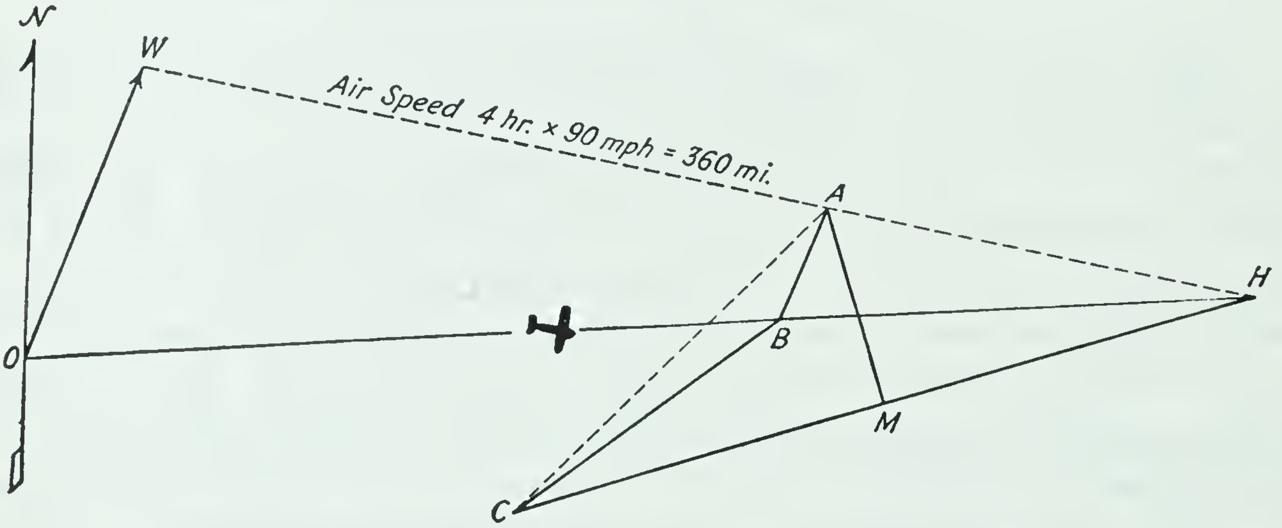


Fig. 309. Return to alternate airport with wind blowing

1. Draw a north-south line and at some point *O* on it lay off *OH* 85° from north.

2. At *O* draw the wind vector for the four-hour period.

3. Open the compasses equal to the airpath for four hours. Place one leg on *W* and cut the course line at *H*. The heading can be measured by extending *W* back to the reference line. It is 100°. *OH* is the track the plane would make if it did not have to turn back to *C*. *WH* is the projected airpath. At some point along the airpath the heading must be changed so the plane can reach *C*.

4. Draw *CH*. Construct the perpendicular bisector of *CH* and extend it to intersect *WH* at *A*. *AC* is equal to *AH* and is the point where the airpath is changed. *AC* is the heading to *C*.

5. Draw *AB* parallel to *OW* and connect *B* and *C*. Triangle *ABC* is the wind triangle for the trip from the time the course is changed until *C* is reached. *AB* is the wind vector and *BC* is the track covered. *B* is the actual point reached before turning from the course *OH*.

6. The air distance *WA* divided by the airspeed gives the time the plane can fly out. *OB* is the radius of action of the plane.

Laboratory Exercise 32. *a.* Use the data given under *a* of Laboratory Exercise 31 with the additional stipulation that the wind is blowing 20 miles per hour from 260°. Find the headings, time of flight out, and distance made good along the course.

b. Use the information contained under *b* of Laboratory Exercise 31, but this time consider the wind to be blowing 30 miles per hour from the south. Find the headings, time of flight out, and distance made good along the course.

c. Plan a problem similar to *c* under Laboratory Exercise 31. The Weather Bureau reports a 20 mile per hour wind from 135°. Make a graph showing the headings, time of flight out, and distance made good along the course.

Return to aircraft carrier—no wind. Aircraft carriers provide a base from which airplanes can take off while at sea and to which they can return after a scouting trip. Ordinarily the carrier continues a steady course after the airplane leaves. The problem then really becomes a radius-of-action problem in which the return is to a second base.

For example, a plane with an airspeed of 75 knots (75 nautical miles per hour) leaves a carrier at a certain point and scouts along a true course of 150°; it must return in 3 hours. The carrier is proceeding 90° true at a rate of 20 knots. If there is no wind, how far can the plane continue on the course before turning back, and at what time after the start of flight will the plane head back toward the carrier?

Figure 310 shows the solution for the problem. It is solved in the following manner:

1. Draw a north-south line. Choose some point *A* on it and lay off from it the course the airplane is to follow. At *D* mark the cruising range of the plane. In 3 hours it could fly 225 miles.

2. Since the carrier is moving, too, draw *AB* to represent the distance it will travel in 3 hours.

3. At some point *P* the airplane must turn back in order to reach the carrier at the end of 3 hours. Draw *BD* and construct the perpendicular bisector of it. Extend the bisector to cut *AD* and draw *PB*. Since *PB* equals *PD, P* is the point at which the airplane must turn back.

4. The aviator has scouted 120 miles of the course in 1 hour 36 minutes. He heads back on a course that is practically true north.

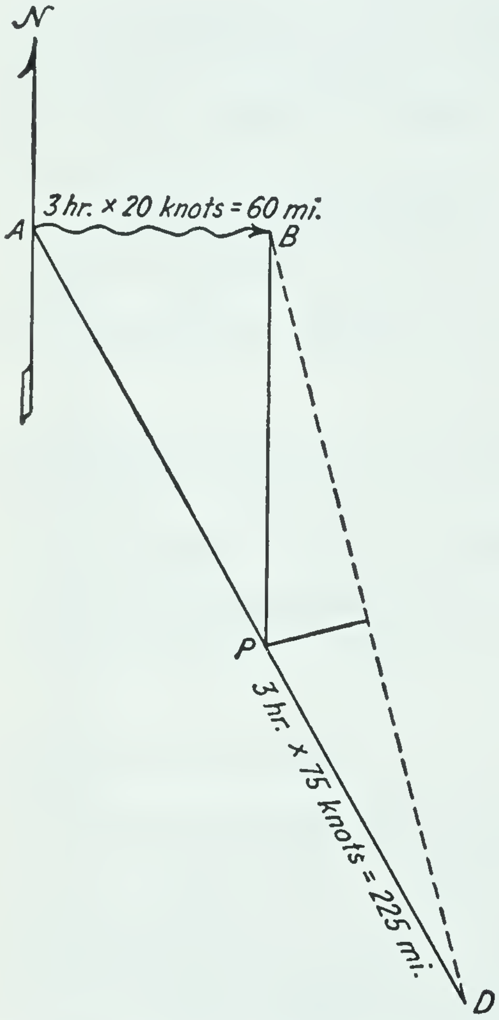


Fig. 310. Return to aircraft carrier when wind is not blowing

Laboratory Exercise 33. *a.* An airplane takes off from an aircraft carrier and flies on a 150° course. The plane has an airspeed of 150 knots and a safe flying time of 3 hours. The aircraft carrier is proceeding on a 210° course at 25 knots. How far can the plane fly on its course and at what time must it turn back toward the point where the carrier will be at the end of 3 hours? What is the heading in?

b. An aircraft carrier is following a 300° course at 22 knots. A plane with an airspeed of 70 knots leaves to scout a 270° course. It has a safe flying time of $3\frac{1}{2}$ hours. How far can it fly on the course and at what time must it turn back? What is the heading on the return flight?

c. An airplane leaves a carrier to scout along a 180° course. Its speed is 110 knots, and it must return in $2\frac{1}{2}$ hours. The carrier has a speed of 30 knots and is proceeding on a course of 105°. At what time must the plane turn back, and how far will it have proceeded on the course? What is the heading back to the carrier?

Return to aircraft carrier when wind is blowing. When an airplane leaves a moving carrier and the wind is blowing, the problem is the same as that of returning to a second base when the wind is blowing.

The following example is a typical problem of this kind. A plane leaves an aircraft carrier at *A* and scouts in a direction 85° from *A* with an airspeed of 100 knots. The wind is blowing 10 knots per hour from the north, and the carrier is proceeding on a course of 125° at 25 knots. The aviator plans to return to the carrier in 3 hours.

At what point must the plane turn back? What are the headings out and back and the time out? The graph for this problem is shown in Figure 311. The procedure is as follows:

1. Select a point A on a north-south line and lay off the true course of 85°.

2. Draw the wind vector AW for the three-hour period.

3. Open the dividers a distance equal to the airpath for 3 hours. Set one leg on W and describe an arc cutting the course at some point D. Draw WD. This is the airpath of the plane if it stayed on the course the full 3 hours.

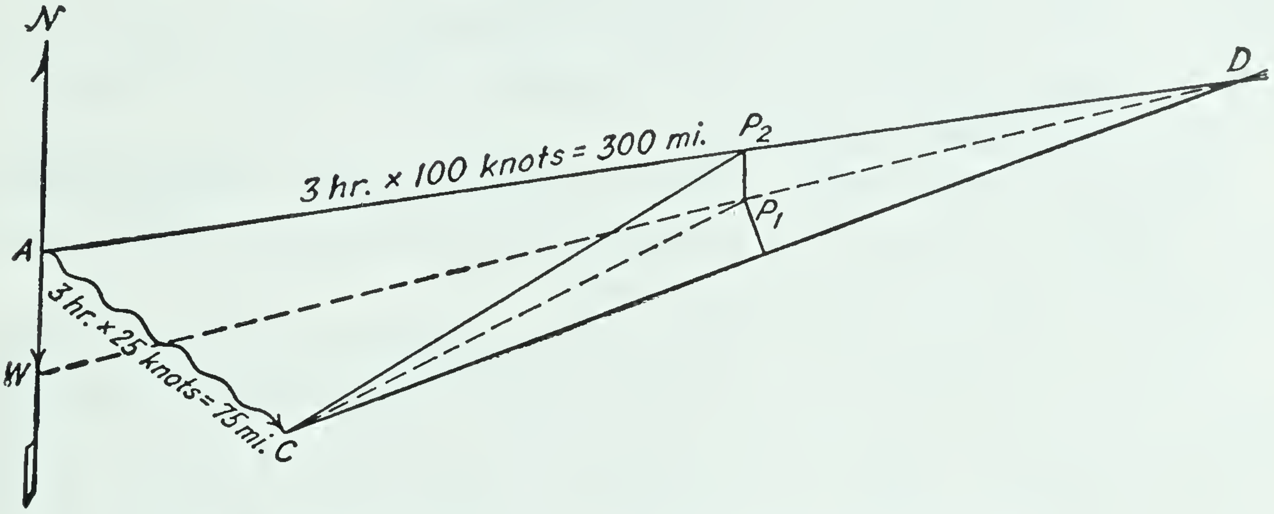


Fig. 311. Return to carrier when wind is blowing

4. Now draw the track of the vessel for 3 hours (AC).

5. Draw CD and construct its perpendicular bisector. Extend the bisector to cut WD. P_1D is equal to P_1C and is the point on the airpath at which the plane must turn back.

6. From P_1 construct a line parallel to the wind and cutting AD at P_2. This is the point which the plane reaches on the course.

7. AP_2 is the distance covered (176 miles).

$$\frac{WP_1}{\text{air speed}} = \text{times out (1.80 hours)}$$

The direction of WD is the heading out (80°). The direction P_1C is the heading in (249°).

Laboratory Exercise 34. *a.* An aircraft carrier is following a course of 160° at a speed of 25 knots. An airplane takes off to scout a course of 40°. The airspeed of the plane is 80 knots, and its safe flying time is 3 hours. The wind is 15 knots from the west. Find the headings out and back, the point at which the plane turns back, and the time of flight out.

b. An airplane leaves a carrier to follow a course of 240°. It has an airspeed of 110 knots and can be gone 4 hours. The wind is blowing 20 knots from the west, and the vessel is steaming south at 30 knots. Find the point at which the plane turns back, the headings, and the time of flight out.

c. An aircraft carrier is making 20 knots on a 210° course. The wind is 15 knots from 50°. If an airplane takes off the carrier on a course of 170° and has an airspeed of 60 knots, what will be the point at which it turns back, the headings, and time of flight out? The safe flying time is $2\frac{1}{2}$ hours.

Airport of least time. Adverse winds or other conditions may retard a flight and make it necessary to fly directly to the airport that can be reached in the least time.

It will be impossible for the pilot to spend much time in plotting a new course, but the co-pilot can by a simple means locate the port that can be reached most quickly. For example, a pilot is flying from Des Moines, Iowa, to Galesburg, Illinois. His airspeed is 90 miles per hour, but he is bucking a 30-mile-an-hour wind from the east. Washington, Iowa, is sighted, and the co-pilot is asked to find the nearest airport that can be reached in 20 minutes flight from it. What airport does the co-pilot select?

Figure 312 illustrates how the pilot proceeds. He locates a point which is marked Washington and lays off *WA*, a 20-minute wind vector. He opens the compass 30 units (20-minute airpath) and describes a circle from *A*. The airport at Iowa City falls within the circle. This is the airport selected by the co-pilot.

If more than one airport had fallen within the circle, a wind vector for a shorter period of time would have been drawn and a correspondingly smaller circle described. If no airports had been found within the circle a longer wind vector would have been drawn and a correspondingly larger radius used.

Laboratory Exercise 35. *a.* An aviator is flying from Omaha, Nebraska, to Howard Airport, at Ames, Iowa. The wind is blowing 35 miles an hour from the south. The airspeed of the plane is 80 miles per hour. When the aviator nears the distinctive highway pattern northwest of Guthrie Center, he decides to land at the nearest airport he can reach within 15 minutes. Which one does he choose?

b. A pilot is flying from Omaha, Nebraska, to Galesburg, Illinois. The wind is blowing 45 miles an hour from 45°. The airspeed of the plane is 100 miles per hour. When the pilot reaches Osceola, Iowa, he decides to fly to the nearest airport. Which one does he select if he has gas for only 20 minutes flight?

c. On a convenient regional or sectional chart plan a flight and determine the nearest airport from some point along the route. Select a suitable wind velocity.

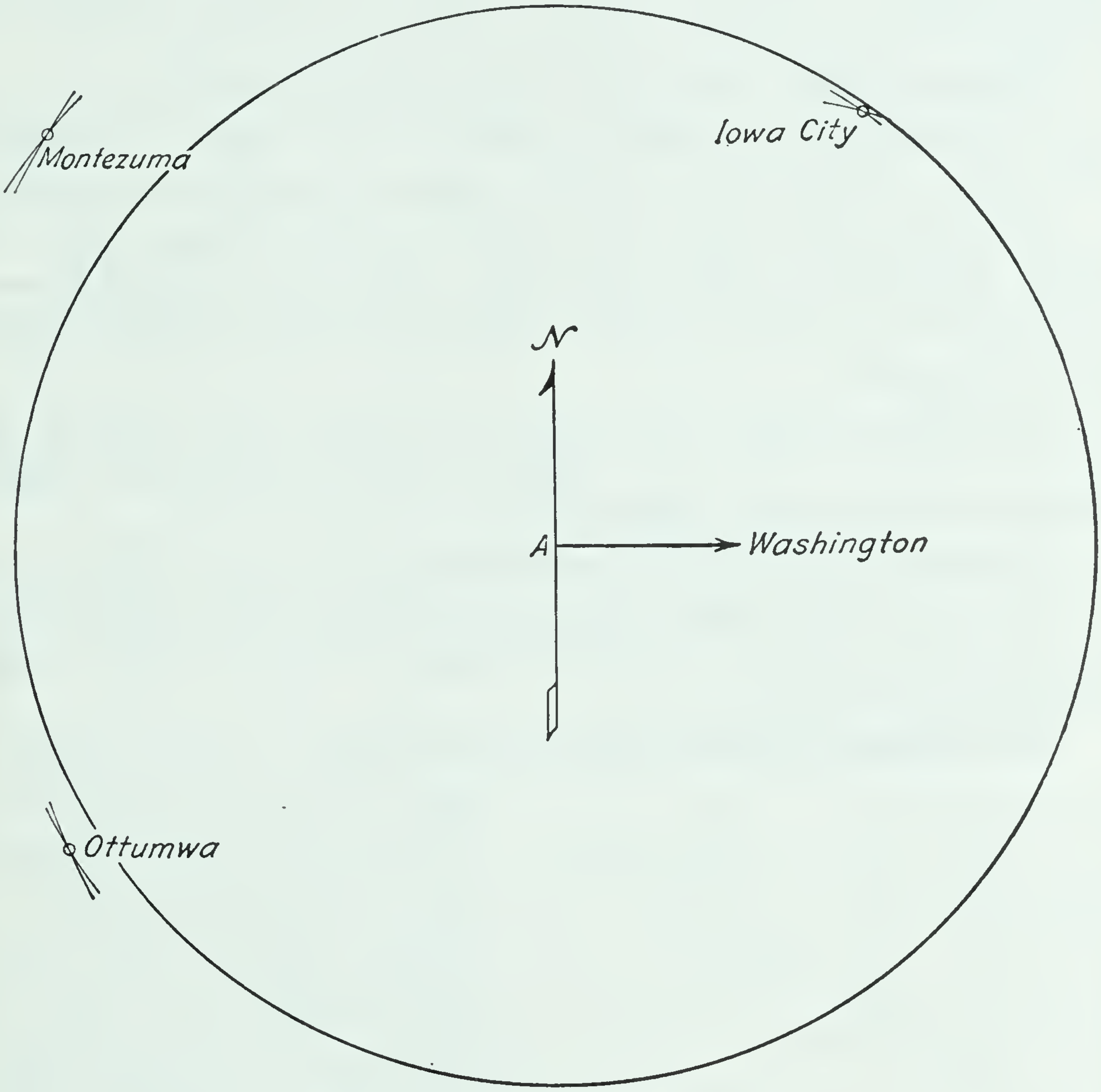


Fig. 312. The airport of least time

Interception problems. The aviator computes the course necessary to intercept a moving body. Problems involving interception may be either commercial or military. The methods of solution will be the same in either case. The purpose of interception may be to make contact with friendly or enemy aircraft, surface vessels, or trains. If the point of contact can be established, the problem is the simple one of determining the heading that will enable the aviator to reach the point at the proper time. Problems of this type can be solved by applying the principles developed in plotting courses from one point to another.

The type of problem to be considered here is the one in which the aviator desires to overtake a moving body in the shortest possible time. In problems of this type, the navigator plots a course that will give a constant line of relative movement between the aircraft and the ship or plane that is being overtaken.

Collision course. The course that will enable the pilot to intercept a moving body is called a collision course. Figure 313 demonstrates the mathematical principle used in solving this problem.

In triangle ABC draw A_1B_1 parallel to AB. Triangles ABC and $A_1B_1C_1$ are similar in shape and angles A and A_1 are equal. Likewise, we can draw A_2B_2 and A_3B_3 and discover that each triangle is similar to the other.

All along the way $\angle A = \angle A_1 = \angle A_2 = \angle A_3$. We can see that the lines AB, A_1B_1, A_2B_2, A_3B_3 are steadily decreasing in length and will finally become a point at C.

Suppose that B is a ship moving along the course BC and that A is an aviator who wishes to fly so as to intercept B. We can see at once that, if he can keep his bearing with B constant, he can intercept the ship at C.

Interception when the wind is not blowing. A ship is proceeding on a 30° course at 30 knots. A pilot on a carrier 100 miles west of the ship is ordered to intercept the vessel as soon as possible. What will be his course if there is no wind, and how soon can he make contact if he has an airspeed of 90 knots?

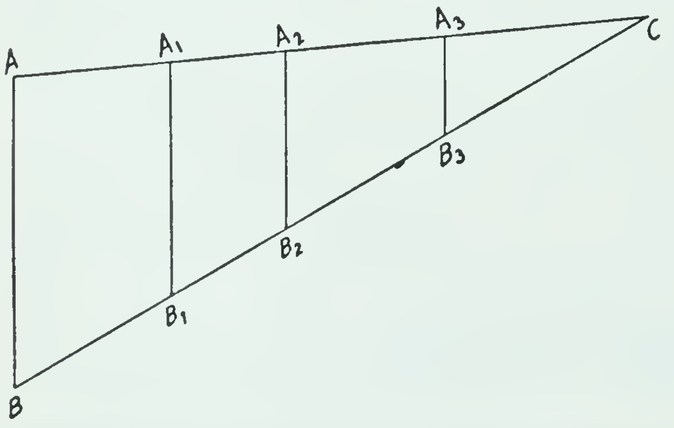


Fig. 313. Constant bearing means collision

Figure 314 illustrates how the constant bearing is found.

1. On a north-south line, place a point S to represent the present position of the ship.

2. Locate A, 100 units west of S.

3. On the course that S is following, measure the distance (30 miles) that the ship steams in 1 hour. Call this point S'.

4. At S' draw a line parallel to AS.

5. Open the compass 90 units to represent the distance the airplane can fly 1 hour in still air. Set the compass at A and describe an arc cutting S^1Y at A^1.

6. Draw AA^1 extended to cut SX at C. C is the point at which the airplane will intercept the ship.

The heading is 72° and the distance SC divided by 30 will give the time $\left(\frac{40}{30} = 1\frac{1}{3} \text{ hours}\right)$.

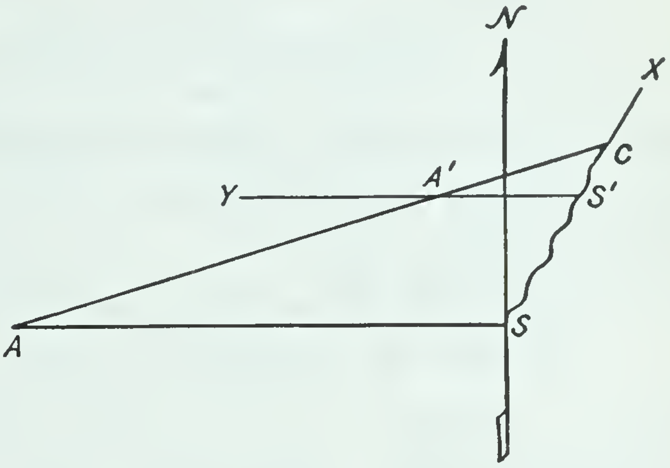


Fig. 314. Finding a constant bearing

Laboratory Exercise 36. *a.* A ship is known to be 150 miles northeast of an airport. It is moving eastward at 30 knots on a still day. How long will it take an airplane with an airspeed of 125 knots to intercept the ship? What will be the heading of the airplane?

b. Omaha, Nebraska, is approximately 265 miles from Wichita, Kansas, and has a bearing of 16° from it. On a calm day, a bombing plane flying 150 miles per hour leaves Omaha flying east. At the same time a pursuit ship with an airspeed of 250 miles per hour leaves Wichita. What will be the heading necessary to intercept the bombing plane, and how soon will it reach the bomber?

c. On a convenient regional chart, place an interception problem involving 2 planes flying on a still day.

Remember that the interceptor must have considerably greater speed than the plane it intercepts; otherwise, it may not be able to cover the additional distance necessary. If this is the case, the compass will not cut the parallel line extended from an hour's flight by the plane to be intercepted.

Another situation which may arise is that the time required for interception may be greater than the time of safe flying of the interceptor.

Interception when wind is blowing. Under ordinary conditions, the course and the heading will not be the same because of the wind. Let us see what would happen in our example for interception with no wind if the wind blew 25 miles an hour from 300°.

Figure 315 gives the graphic solution. The general form of the solution is the same as before. The only difference is that a wind vector must be drawn.

The steps in setting up the graph are as follows:

1. On a north-south line place a point S to represent the ship.
2. Lay off the course SX of the ship, and 100 units west of S mark A, the position of the airplane. Connect A and S.
3. Mark S_1 the distance the ship travels in 1 hour, and mark YS_1 parallel to AS.
4. Lay off the wind vector AW for a drift of 1 hour.
5. Open the compass 90 units. Set one leg at W and describe an arc cutting YS_1 at A_1. WA_1 is the heading and A_1 is the point which the plane must pass over in order to intercept the ship.
6. Draw AA_1 (this is the distance the plane makes over the ground in 1 hour) and extend the line to cut SX at C. C is the point of interception.

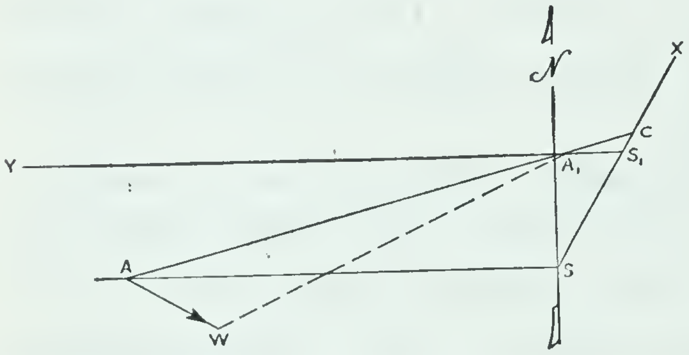


Fig. 315. Finding a constant bearing when the wind is blowing

The heading is measured by the angle WA_1 makes with the north-south line (69°). The time is found by dividing the units of line AC by those of AA_1. It is approximately 1 hour 24 minutes.

Laboratory Exercise 37. *a.* Find the heading and time of interception in Laboratory Exercise 36 a, if there is a 25-mile-an-hour wind from the south. Assume that the plane to be intercepted has made the necessary allowance and is staying on course.

b. Fort Wayne, Indiana, is 600 miles from Lincoln, Nebraska, on a course of approximately 88°. A plane leaves Fort Wayne on a 200° course with a ground speed of 150 miles per hour. The wind is 30 miles per hour from the north. What is the heading necessary for a plane leaving the airport at Lincoln at the same time to intercept the one leaving Fort Wayne if it has an airspeed of 250 miles per hour?

c. Denver, Colorado, is 800 miles from Randolph Field. The bearing of Denver from Randolph Field is approximately 330°. A plane leaves Denver flying at a ground speed of 200 miles per hour on a 90° course. At the same time, an interceptor plane with an airspeed of 250 miles per hour takes off from Randolph Field.

There is a 30-mile-an-hour wind from the west. How soon can the plane intercept the one flying from Denver, and what should be the heading?

Problem 7. How is the radio used to aid air navigation?

Radio navigation. Radio navigation is the third method of air navigation and is an additional help in solving the problem of flying from here to there. The radio-range system is an aid to dead reckoning. Excessive static or mechanical failure may deprive the pilot of the radio range; therefore, it is important for the pilot to keep a record of compass headings and positions.

The pilot who follows the radio-range course does not need to make corrections for drift; all that is necessary is to head the plane at an angle sufficient to hold the plane on course. The difference between the heading finally arrived at in this way and the no-wind heading required to follow the range course is the drift angle. This information would be valuable if it were necessary to return to dead reckoning.

Average bisector. The section on radio communication explained how the stations send out beams on four quadrants. When an aviator picks up a beam from a station, he must be able to identify the quadrant in order to locate his position. Most methods of orientation make use of the average bisector. From our geometry, we recall that to bisect means to divide in half. Hence, a true quadrant bisector divides the quadrant in half. The quadrants, however, are not true quadrants. They are usually laid out with reference to other stations and, as a result, may contain more or fewer than 90°.

In Figure 316 we find that the north quadrant extends from 333° to 53°. This is a spread of 80°. The bisection course for north *N* quadrant is 13° or 193° depending on whether the pilot is flying toward or away from the beam.

This course is the bisecting course of the north *N* quadrant. The south *N* quadrant, on the other hand, lies between 270° and 198°. The bisector of this quadrant is 54° or 234°, again depending upon the direction the pilot is flying. If a pilot is lost and picks up an *N* signal, he cannot assume that he is in a certain position; he must fly a course that can apply to either quadrant. For this purpose, the average of the two bisectors is taken

$$\frac{13^\circ + 54^\circ}{2} = 33\tfrac{1}{2}^\circ$$

$$\frac{193^\circ + 234^\circ}{2} = 213\tfrac{1}{2}^\circ$$

The courses are usually determined to the nearest 5°; therefore, the average bisector for the *N* quadrant is 35° or 215°.

The average bisectors are always 90° apart; hence, the average bisector for the *A* quadrant is 125° or 305°.

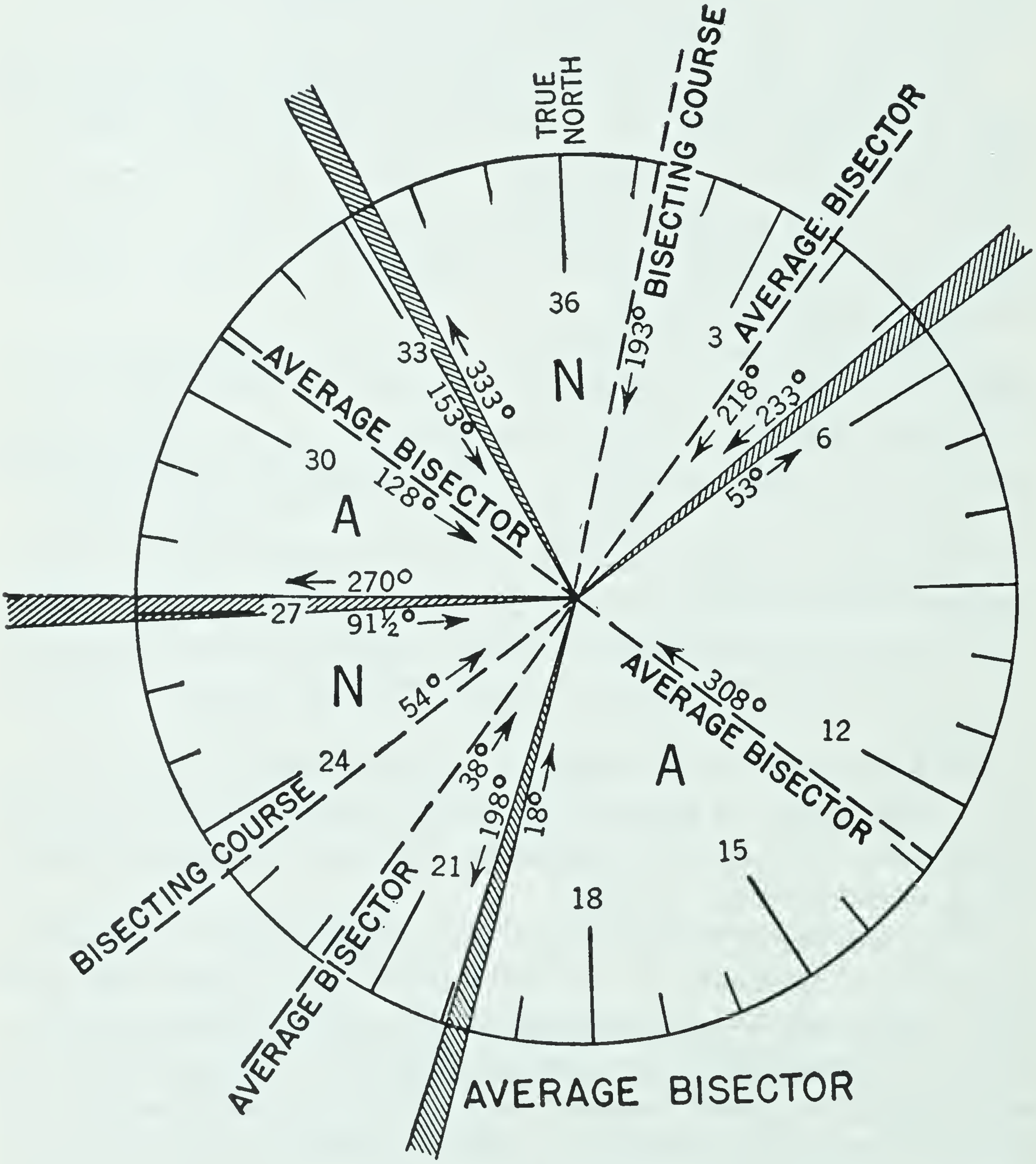


Fig. 316

Since the on-course zones of the various radio-range stations are pointed in different directions, it is necessary to calculate the average bisectors for each one.

Laboratory Exercise 38. *a.* Find the average bisectors for the radio-range station at Omaha, Nebraska.

b. What are the average bisecting courses at the Des Moines, Iowa, radio-range station? (The easterly range course at Des Moines is the reciprocal of the westerly course.)

Orientation. The pilot can identify his position by methods of orientation. When the pilot picks up a range signal, he can make use of one of the following means of determining the quadrant in which he is flying.

90° method. This is a simple method of orientation and was one of the first to be used. It can be used successfully when the quadrants of the range are close to 90°. The course is flown at right angles to the average bisector of the two possible quadrants. It is especially important to use the average bisector since this course is equally suitable for either quadrant.

If an aviator is receiving the *A* signal from a station which he knows to be Burlington, Iowa, he will proceed as shown in Figure 317. The average bisector of the *A* quadrants is either 30° or 210°. (These are the magnetic bearings.) The course at right angles is 120° or 300°. If the course of 300° is selected, then it is certain that courses two and three are somewhere behind the airplane.

The pilot continues on the course of 300° until the on-course signal is heard. He passes through the on-course signal until he hears the first *N* signal of the other side; then he makes a 90° turn to the right.

He has crossed either course one or course two. If it is two, the *N* signal continues after the turn; if it is course one, the on-course signals will be heard again, followed by the *A* signal. The signals definitely identify the course intercepted.

Next the pilot makes a general turn to the left, away from the station, and gradually eases into the equi-signal zone which he follows to the station and from that point on to the local airport or a more distant destination. A pilot approaching a radio-range station may fly in the on-course zone, but pilots flying from a station are required to fly to the right of the equi-signal zone.

If the course of 120° is selected, the procedure would be the same as that just described for 300°.

We have assumed that the pilot was near the center of an *A* quadrant; now, suppose he is near enough to one of the range courses to hear faintly the *N* signal as well as the *A* signal. This means he is either just north of course two or course three, or just south of course four or course one. If he flies the 300° course at right angles to the average bisector of the quadrants and the faint signal begins to fade, he knows that he is flying away from the nearest on-course zone. Therefore, he is just north of course two or course three; he makes a 180° turn, approaching the equi-signal zone on the 120° course. The procedure from then on is the same as that shown in Figure 317.

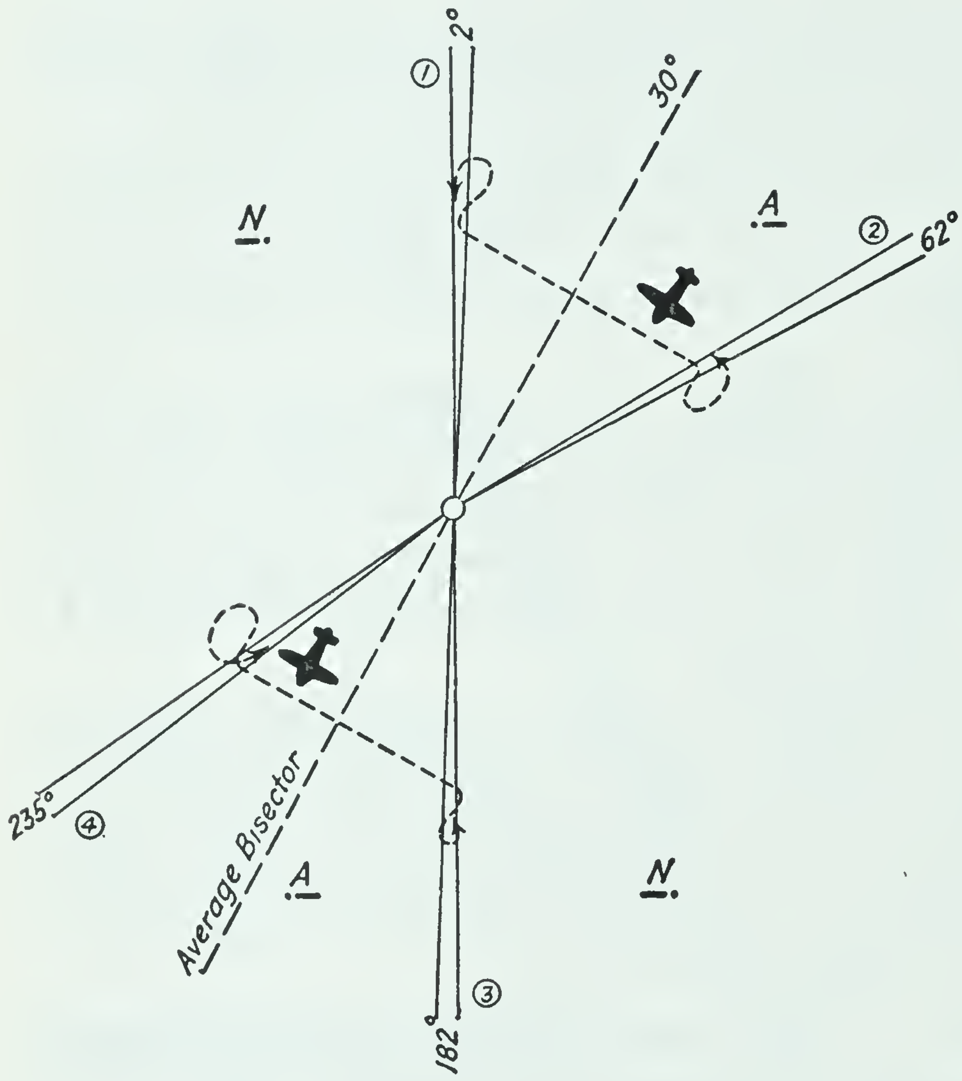


Fig. 317. 90° method of orientation

If the pilot flies the 300° course and the faint signal becomes stronger, he knows he is approaching the equi-signal zone and that he must be just south of course four or course one. He continues on his heading and carries out the procedure which is shown graphically in the figure.

The 90° method is dependable. Flying a course at right angles to the average bisector of the quadrants may make it necessary, however, to fly a considerable distance before picking up the on-course signals. This is the disadvantage of the 90° method.

The fade-out method. The pilot who uses this system flies a course parallel to the average bisector of the two quadrants with the volume of his receiver as low as possible. If the signal fades out, he knows that he is flying away from the station; if the volume increases, he knows he is approaching it.

For example, in Figure 318, if a pilot is flying a course of 30° and the signal fades out, he knows he is in the easterly *A* quadrant with the station behind him. He makes a 180° turn and flies to and through an equi-signal zone. As soon as the first *N* signal is heard, he turns left not more than 180°, until the on-course signal is again received.

With volume as low as practicable, he straightens out along the right side of the range course and flies until the volume fades out or builds up appreciably. If it is increasing, he follows it into the station; if it fades out, he makes a 180° turn and follows it in to the station.

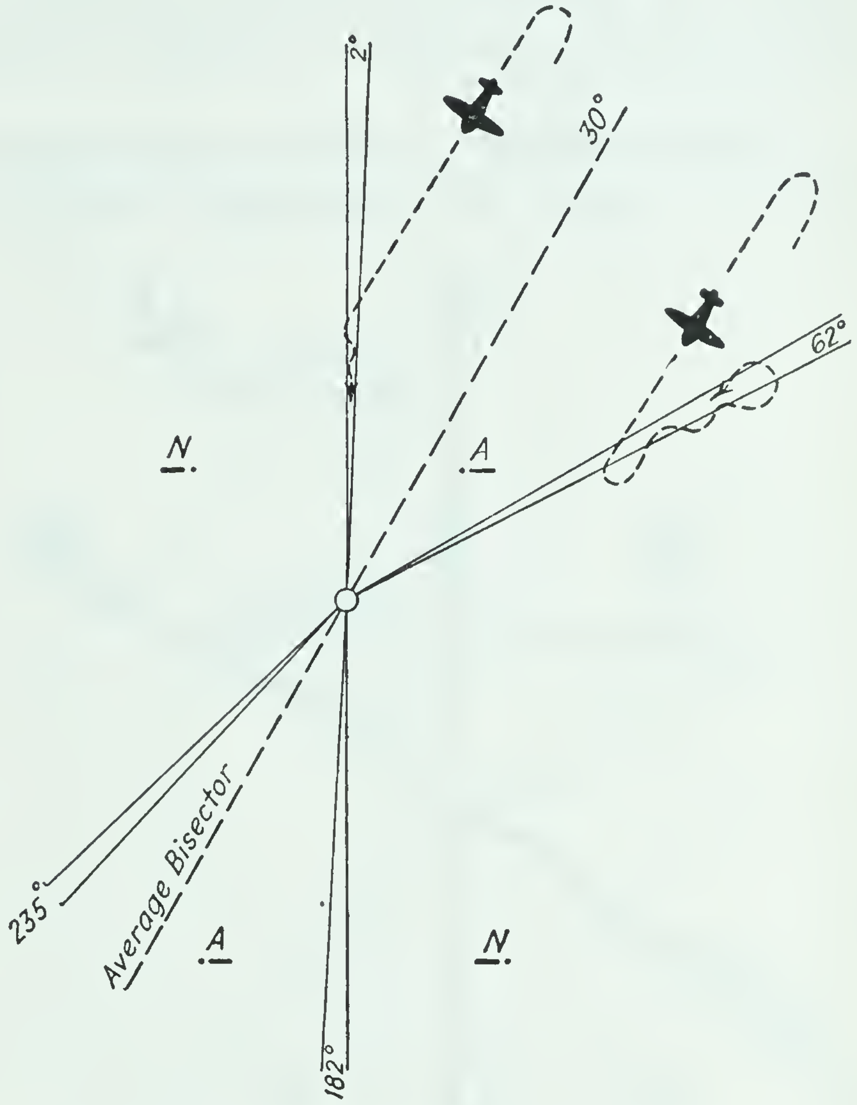


Fig. 318. Fade-out method of orientation

The signal strength is sometimes variable, and this makes it difficult to decide without considerable loss of time whether the volume is increasing or decreasing. Another weakness of this method is that when the courses are squeezed (less than 90° apart) it is possible to fly away from a station and have the signals become stronger, instead of weaker.

The greatest signal strength is always found along the bisectors of the quadrants, and the lowest signal strength is found along the edges where the on-course zones are located. For this reason, when the pilot is flying parallel to the bisector, but at a considerable distance from it, the signal strength may decrease as the on-course is approached, even though the station is nearer. If the decreased signal strength is a result of approaching an on-course zone, the double signals of the twilight zone should be heard upon turning up the volume. If the twilight signals are not heard with the increased volume, the pilot knows definitely that he is flying away from the station. In either event, he can identify the quadrant and may proceed as shown in Figure 318.

Parallel method. The pilot identifies the quadrant in the same manner as in the fade-out method; then he flies parallel to one on-course to intercept another on-course. After the pilot has selected the on-course he desires to fly to the station, he flies parallel to the other on-course forming the quadrant until he reaches the desired on-course. He then flies on the right edge of the beam to the station. Figure 319 illustrates the procedure to be followed.

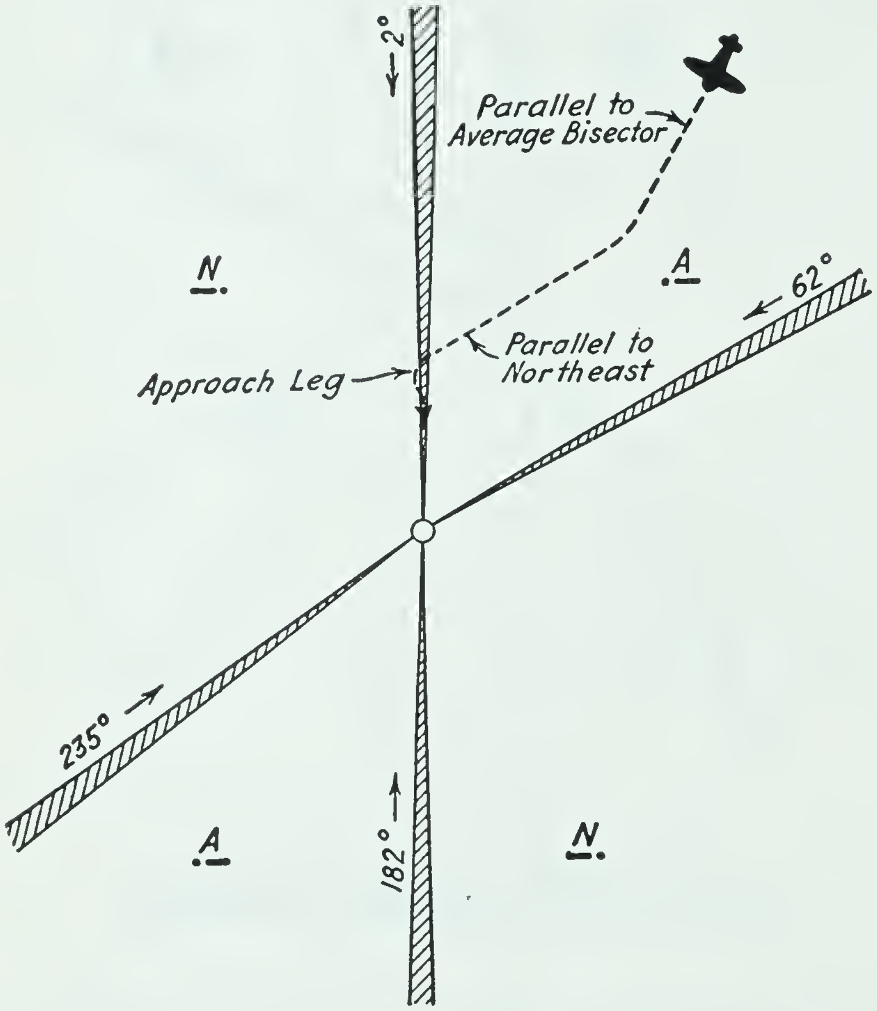


Fig. 319. The parallel method of orientation

If a station has a wide quadrant, the pilot should not start a course parallel to the first on-course too soon after picking it up. This is particularly true if there is a strong wind from the station.

Combination method. A combination of the foregoing methods is frequently advantageous. This prevents confusion and loss of time in deciding which method is the most suitable to use in a certain situation. This method has been adopted as standard by some of the major air lines because it can be used satisfactorily on all ranges.

The quadrant is identified by the fade-out method, and the airplane is headed parallel to the bisector, toward the station. Figure

320 shows that the plane will intercept either course one or course two which can be followed to the station.

Effect of wind on turns. High winds produce drifts that affect some of the orientation problems. Figure 321 shows the effect of a strong westerly wind. In this case a wind of 80 miles per hour is assumed, and the airplane is assumed to have an air speed of 110 miles per hour.

At course one, the airplane will not follow the light broken line and return to the range, but will follow the heavy line.

On course two, the airplane will be able to get back on course after flying somewhat farther than would normally be required.

On course three, the drift would keep the pilot in the on-course zone so long that he would doubt if his turn would produce the desired result. He might even believe himself to be on course two.

At course four, as at course one, it is unlikely that the airplane would ever return to the range course.

These extreme conditions are not likely to be experienced in practice. They serve to emphasize the effect of wind in turns. A pilot should make every effort to know the wind at all times during flight, and to visualize the effect of the wind upon the headings flown or the maneuvers performed.

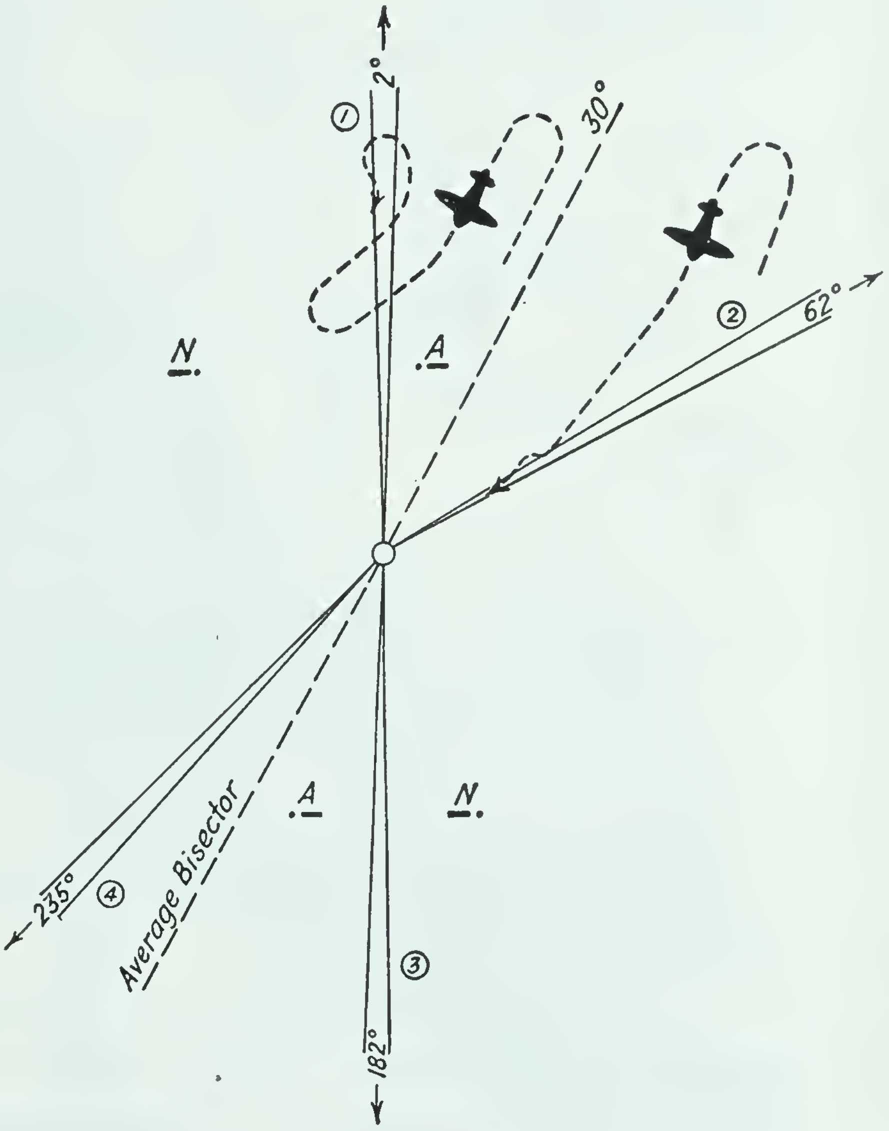


Fig. 320. The combination method of orientation

Radio in instrument landings. Radio ranges are used to effect instrument landings. Since 1928, experimental work on instrument

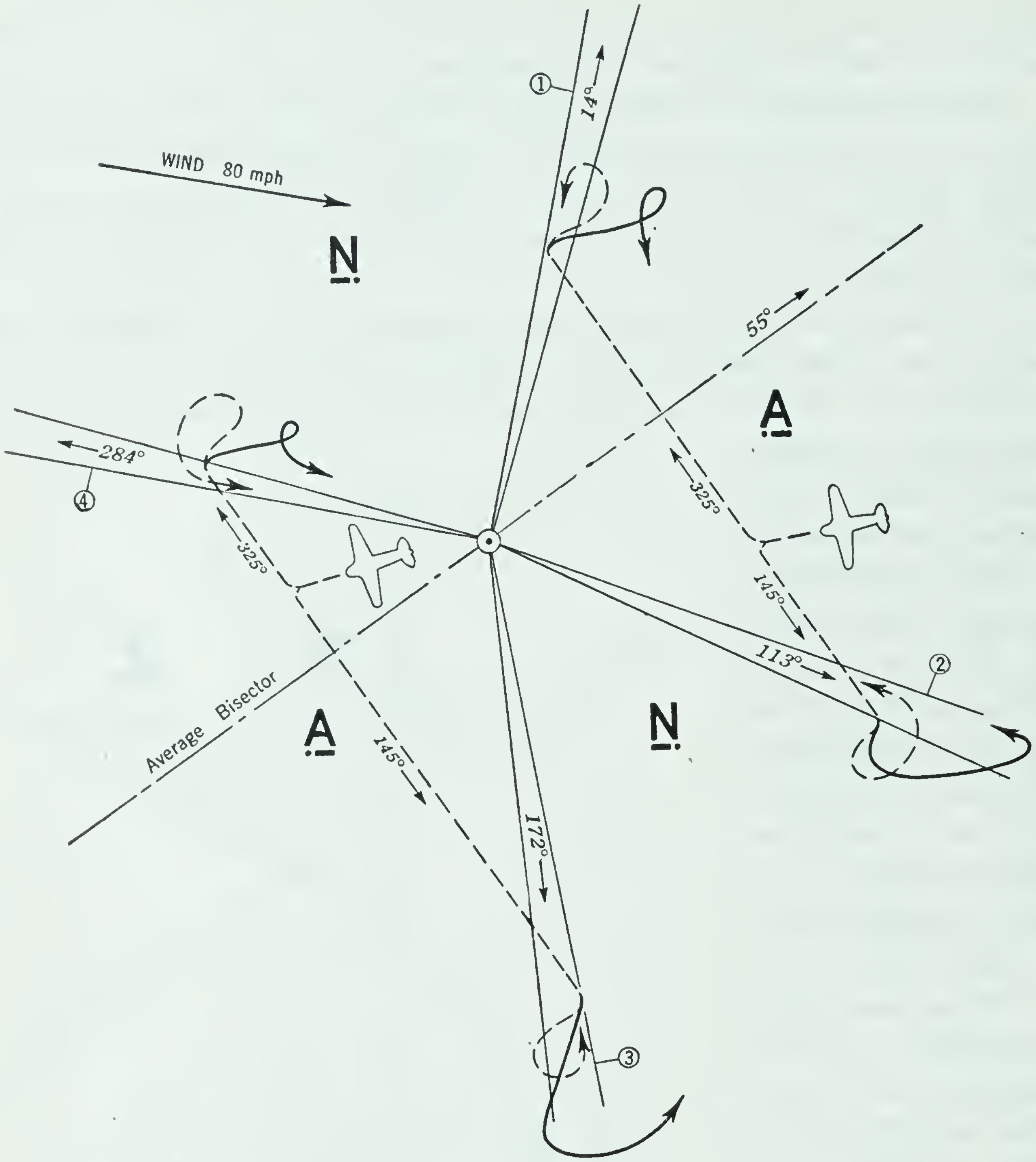


Fig. 321. Effect of wind on turns in orientation procedure

landings has been under way. No one best method has been developed, but the general principle of all is that through use of instruments the plane follows a range course to the landing field.

The following description is of the experimental system set up at Indianapolis:

The system consists of four fundamental elements: a runway localizer, which provides a range course for lateral guidance; a glide path, which provides a means for descent; and two vertical marker beacons to indicate the progress of approach to the landing field.

The runway localizer provides a beam which forms an imaginary vertical plane extending along the center line of the runway in the

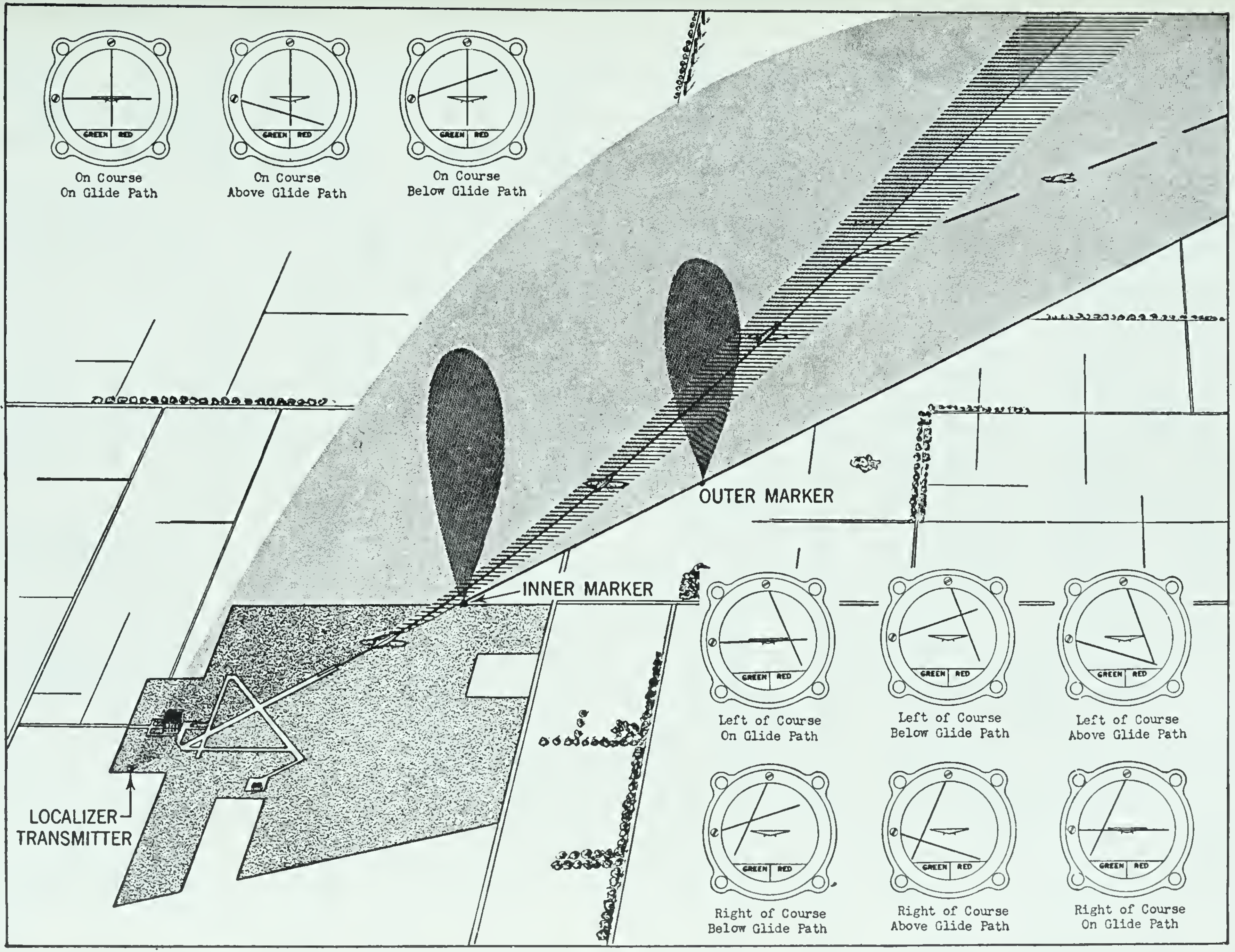


Fig. 322. Indianapolis instrument landing system

direction of approach. The landing instrument in the airplane has a vertical needle which indicates when the plane swings to the right or to the left of this beam.

The glide path is a beam which curves from the landing runway upward at an angle of three or four degrees. Five miles from the runway this path is approximately 1500 feet above ground. The landing instrument has a horizontal pointer which indicates when the airplane is above or below the glide path. The insets in Figure 322 show instrument readings.

An imaginary line is formed by the intersection of these two surfaces. It curves upward for many miles from the end of the runway. The flight instrument previously described enables the pilot to fly his airplane downward along this line with a high degree of precision.

Problem 8. How does the aviator use celestial navigation?

The development of transoceanic airways emphasizes the importance of determining position on the earth from observations of the sun, moon, stars, and other planets. Sailors have long used this method of locating the position of ships at sea and of plotting their course for distant points.

With present methods and equipment, celestial navigation will not be of practical importance for flights of from 500 to 1000 miles. Even the transoceanic routes are being equipped with radio facilities. Many persons believe that radio will provide the leading navigational aid in air transportation and that celestial navigation will grow less important. It is necessary, however, for the pilot to understand and practice celestial navigation in case the radio service fails.

Celestial navigation is not difficult; in fact, the most difficult part of the process is the taking of the sextant observation. Four steps are necessary in the determining of a position; (1) observation with a sextant, (2) noting the exact time of the observation, (3) computation of the line of position from the sextant observation and the time it was made, and (4) the plotting of the line of position on the chart. The computations may be done by arithmetic, and the plotting of the position line is as easy as measuring the course angle.

The skill of the observer, the instrumental equipment, and the conditions under which the sextant observations are taken all affect the accuracy of the results. A surveyor making use of astronomical observations can determine the geographic location of his position within a few yards. The position of a ship at sea can be determined within a mile or two. The average accuracy of the position of an airplane is from five to ten miles. Since a single observation may have a considerable error, it is common practice to take the average of five or ten readings.

Basic principles. Most people can point out the North Star. Some speak of it as the Pole Star. It is more properly known as Polaris. This star is almost directly above the North Pole. An observer at the North Pole would see Polaris almost exactly overhead, that is 90° above the horizon. If the observer moves southward 15°, to latitude 75°, the altitude of the star is found to be 75°. The altitude is found to be 75° at any point on the parallel; therefore, the 75th parallel is a circle of position. The same thing will be found true on the 25th parallel; at any point on this parallel the altitude of the North Star is 25°. At the equator this angle becomes zero, and beyond the equator the North Star is not visible.

From the foregoing discussion, we can draw the following conclusions that will apply to all stars:

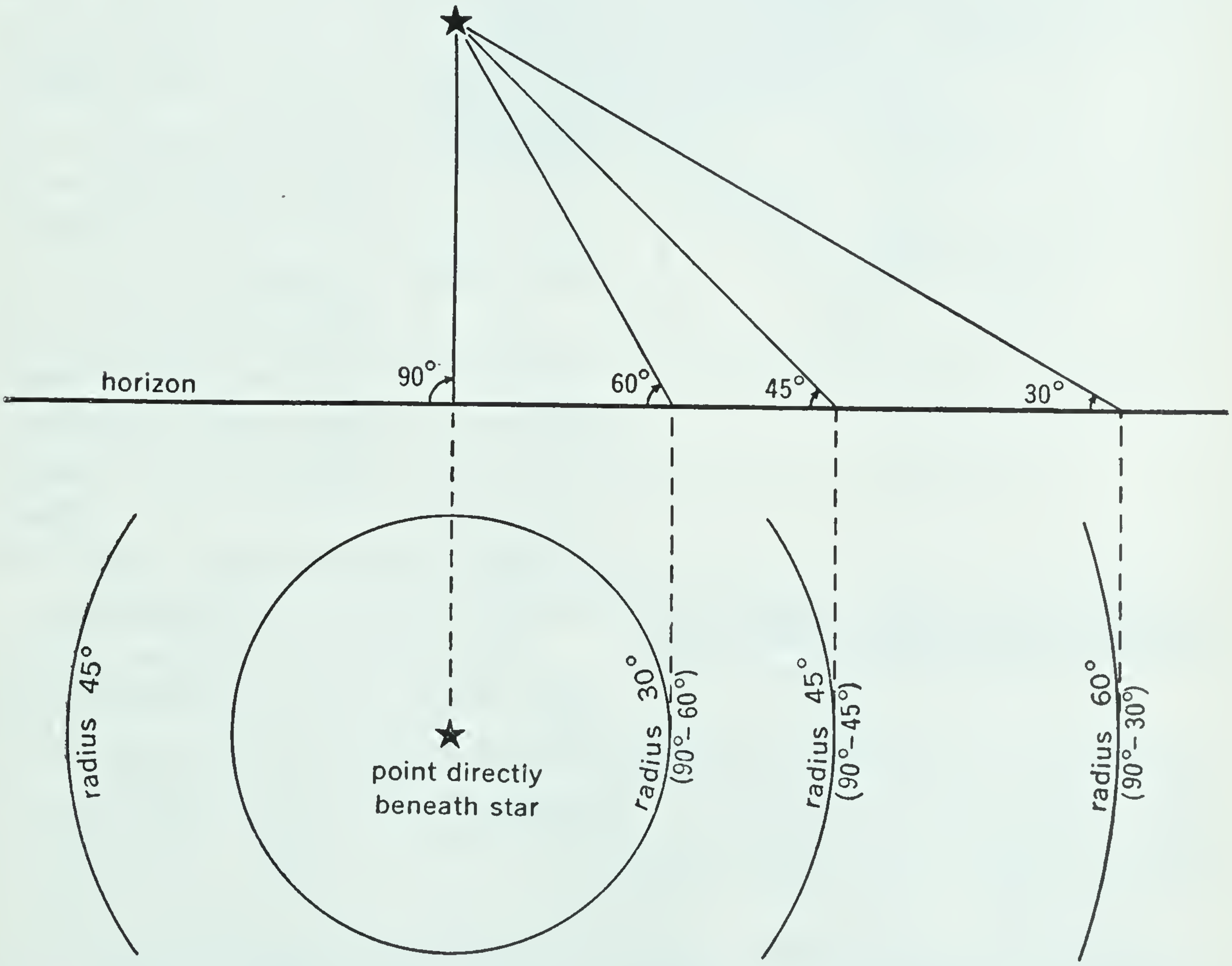


Fig. 323. Relation between observed altitudes of a star and circles of position

1. Directly beneath each star is a point which is the center of a system of concentric circles of position.

2. The altitude of a star is the same at any point on a given circle.

3. The altitude of the star decreases in direct proportion to the angular distance from the point directly beneath the star. For example, if we move away a distance equal to 5° of latitude the altitude decreases 5°.

4. The radius of the circle of position is equal to 90° minus the observed altitude. (The radius is given in degrees of latitude.)

Figure 323 illustrates the conclusions just drawn and shows how these principles apply to all stars. Other stars do not have the north pole as the point of center. Their center is the point that happens to be directly beneath them.

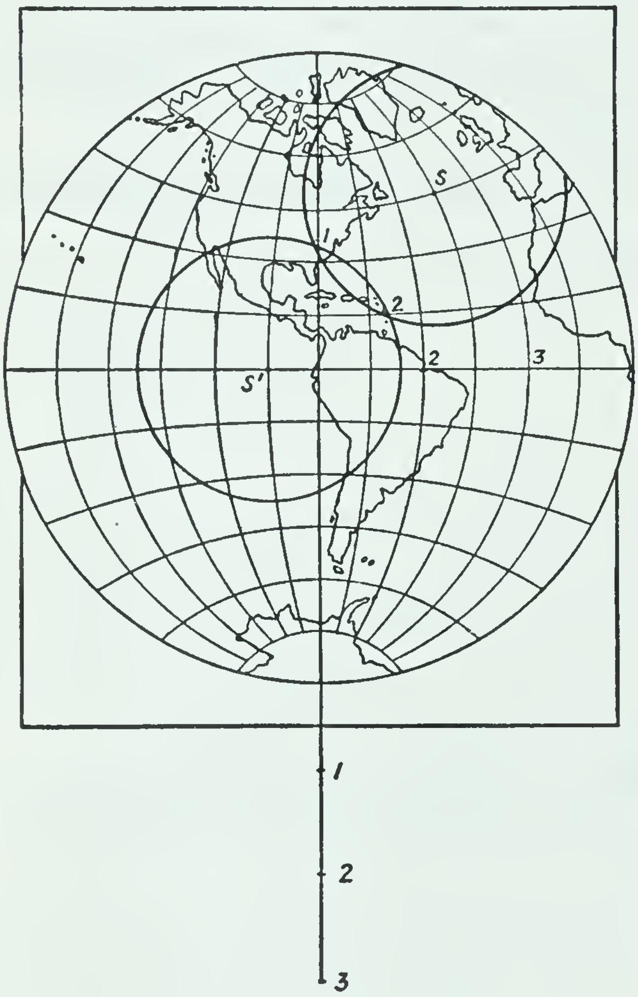


Fig. 324. Determining position by drawing circles of altitude with reference to celestial bodies

Suppose now that the pilot determines a circle of position for each of two stars. It is obvious that his position is on each of the circles. For that reason, his position is definitely located at the intersection of the circles. It is true that the circles intersect at two points, but one of them can usually be dismissed as being an impossible solution. Figure 324 shows how these circles might appear.

On a large-scale chart, the navigator starts with an assumed position. He then makes his observations and determines his line of position by drawing it as a short straight line across what would be a radius of a circle of position.

Since a line of position from a single star does not definitely fix a position, it is necessary to obtain lines of position from two or more stars. Because of inaccuracies of observation, the lines from three or more seldom meet at a point, but usually form a triangle. The position lies somewhere within this triangle.

Celestial co-ordinates. Planets and stars are located by reference to celestial co-ordinates. In order to solve the problems of celestial navigation, it is necessary to have a system of celestial co-ordinates that correspond to latitude and longitude on the earth. The sky at night appears to be a star-studded bowl inverted over the earth. For our purpose, we may think of the earth as the center of a heavenly sphere. Figure 325 shows this celestial sphere.

The extended axis of the earth cuts the celestial sphere in two points which are called the north and south celestial poles. The celestial bodies, with the exception of the planets and the moon, do not appear to change their position with respect to the earth. (Measurable changes take place during a long time interval such as a century.) The rotation of the earth makes the celestial bodies appear to rise in the eastern and set in the western parts of the earth's horizon, so that the celestial sphere has the appearance of rotating about the celestial axis.

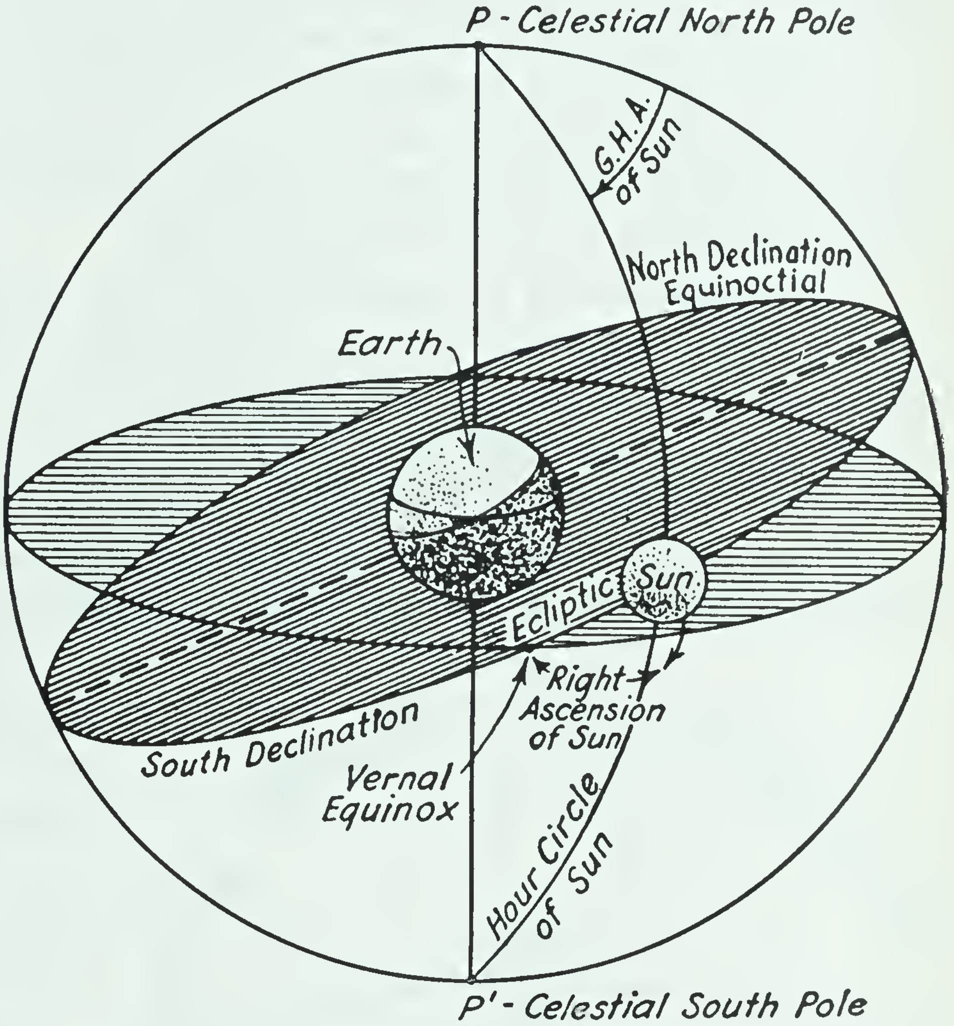


Fig. 325. The celestial sphere

The plane of the earth's equator is extended to intersect the celestial sphere and form the celestial equator. The celestial equator (or equinoctial) is everywhere 90° from the celestial poles just as the equator of the earth is 90° from the earth's poles.

Distance north or south of the celestial equator is known as declination. Declination corresponds to latitude on the earth and is measured in degrees of arc. North declination is given a plus sign, and south declination has a minus sign.

A great circle that passes through a place on the earth and both poles is a meridian. On the celestial sphere, a great circle that passes through a celestial body and the celestial poles is known either as a meridian or as an hour circle.

The point known as the vernal equinox is used as the zero point for measuring right ascension in the heavens. Right ascension is the arc measured along the celestial equator between an hour circle passing through the vernal equinox and an hour circle passing through some other celestial body. It is always measured to the eastward. The position of a star or other heavenly body may then be fixed in the heavens by knowing its right ascension and its declination.

The zenith of a place on the earth is the point in the celestial sphere that is directly overhead. The altitude of a star is its angular distance above the celestial horizon, measured on a vertical circle passing through the zenith and the star.

The *azimuth* of a celestial body is the angle between the celestial meridian and the vertical circle (great circle) passing through the body. It is measured on the celestial horizon counting from north like any terrestrial bearing.

Polar distance is the angular distance from a celestial pole measured on the hour circle passing through the celestial body. It is equal to 90° plus or minus the declination of the celestial body.

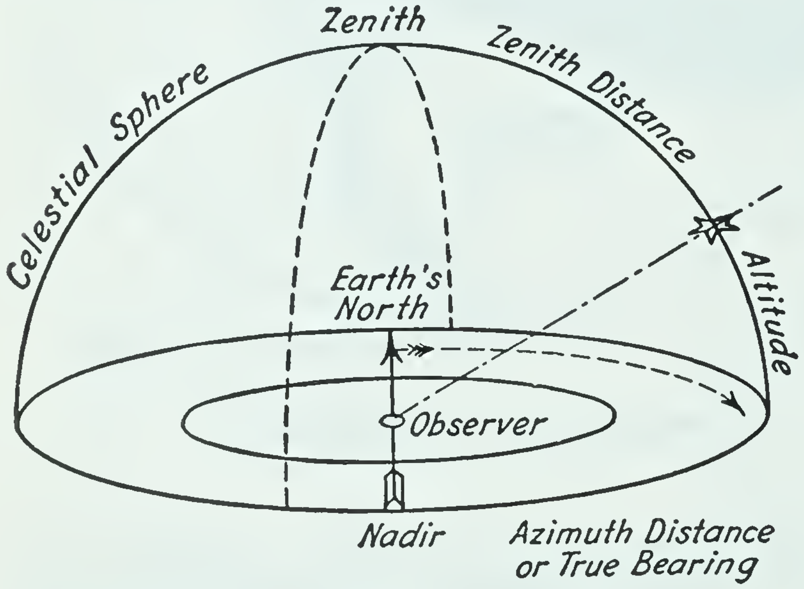


Fig. 326. Finding the position of a star

Zenith distance is the angular distance from the zenith measured on the vertical circle passing through the celestial body. It is equal to 90° minus the altitude.

Sextant observations. The sextant observation is an important step in celestial navigation. No matter how accurate the computations may be, if the observation is inaccurate, the line of position will be inaccurate. Good sextant observations are largely a matter of practice, and of familiarity with the instrument.

A bubble sextant is the most suitable for aircraft use because a visual horizon is not always available when observations are made. The bubble provides an artificial horizon which can be used as reference. When the instrument is in a level position, the edge of the bubble is concentric to a circle engraved in the center of the sextant field. In measuring altitude, the celestial body is brought into a position coinciding with the center of the bubble.

Hour angle. The hour angle of a point may be defined as the difference of longitude between the point and another meridian of reference.

Comparison of terrestrial sphere and celestial sphere

TERRESTRIAL SPHERE	CELESTIAL SPHERE
North Pole	North Pole
South Pole	South Pole
Equator	Equator
Latitude:	Declination:
North Latitude:	North Declination (+):
0° to 90° north of equator	0° to 90° north of celestial equator
South Latitude:	South Declination (—):
0° to 90° south of equator	0° to 90° south of celestial equator
Longitude:	Right Ascension:
Reckoned from Greenwich	Reckoned eastward from vernal equinox, or first point of Aries
0° to 180° east or west of Greenwich	0^h to 24^h east of vernal equinox
0^h to 12^h east or west of Greenwich	
	Sidereal Hour Angle:
	Reckoned westward from vernal equinox
	0° to 360° west of vernal equinox
	Greenwich Hour Angle:
	Difference of longitude between the point directly beneath the body and the meridian of Greenwich
	Local Hour Angle:
	Difference of longitude between the point directly beneath the body and the observer's meridian

The difference of longitude between the meridian of a point directly beneath the observed body and the meridian of Greenwich is known as the Greenwich hour angle. The difference of longitude between the point directly beneath the observed body and the meridian passing through the observer's position is known as the local hour angle.

Hour angle may be expressed either in terms of hours, minutes, and seconds of time, or in terms of degrees, minutes, and seconds of arc. Greenwich hour angle is always measured westward from Greenwich from 0^h to 24^h, or from 0° to 360°. Local hour angle, like longitude, is measured east or west from the observer's meridian, from 0^h to 12^h, or from 0° to 180°.

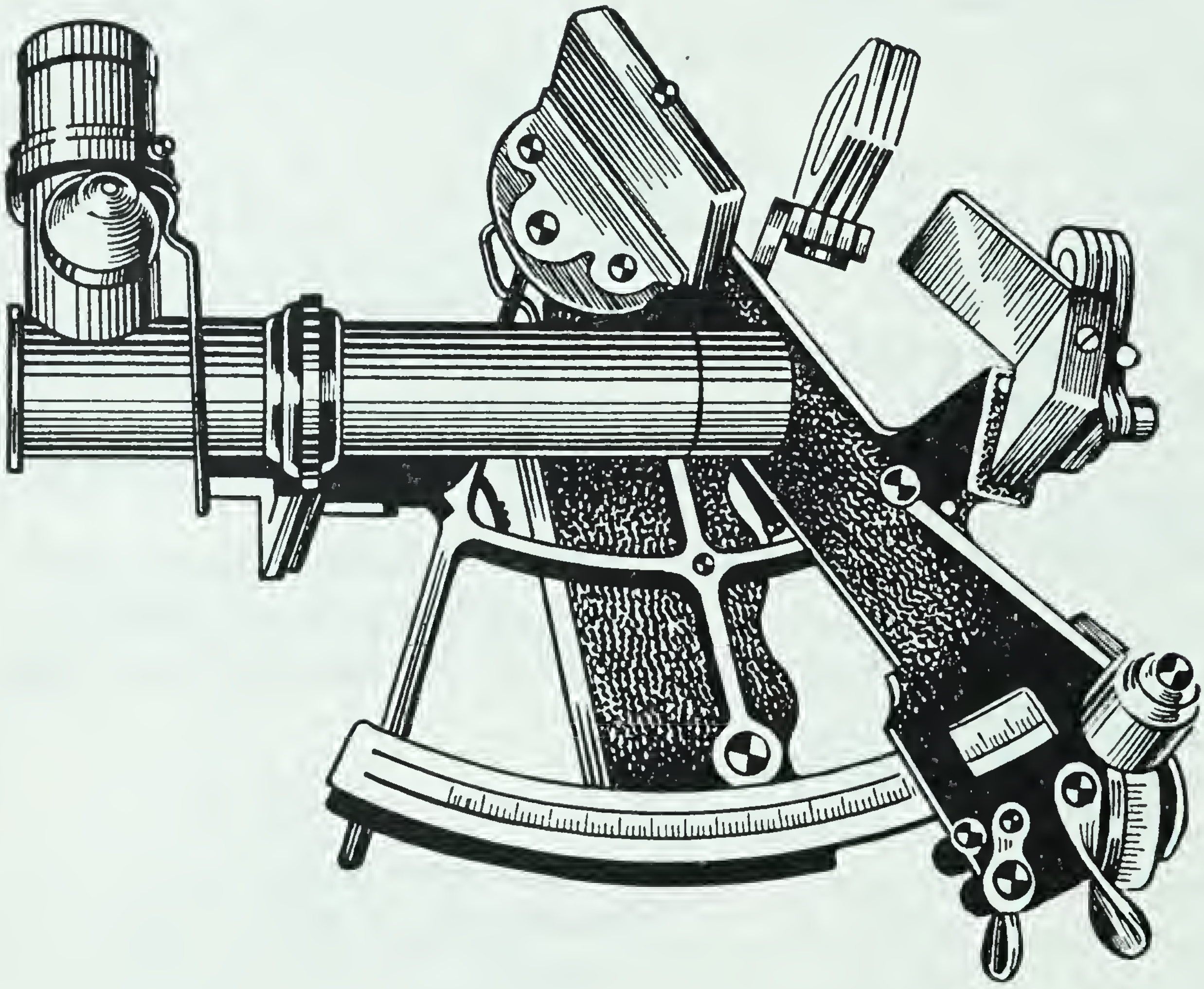
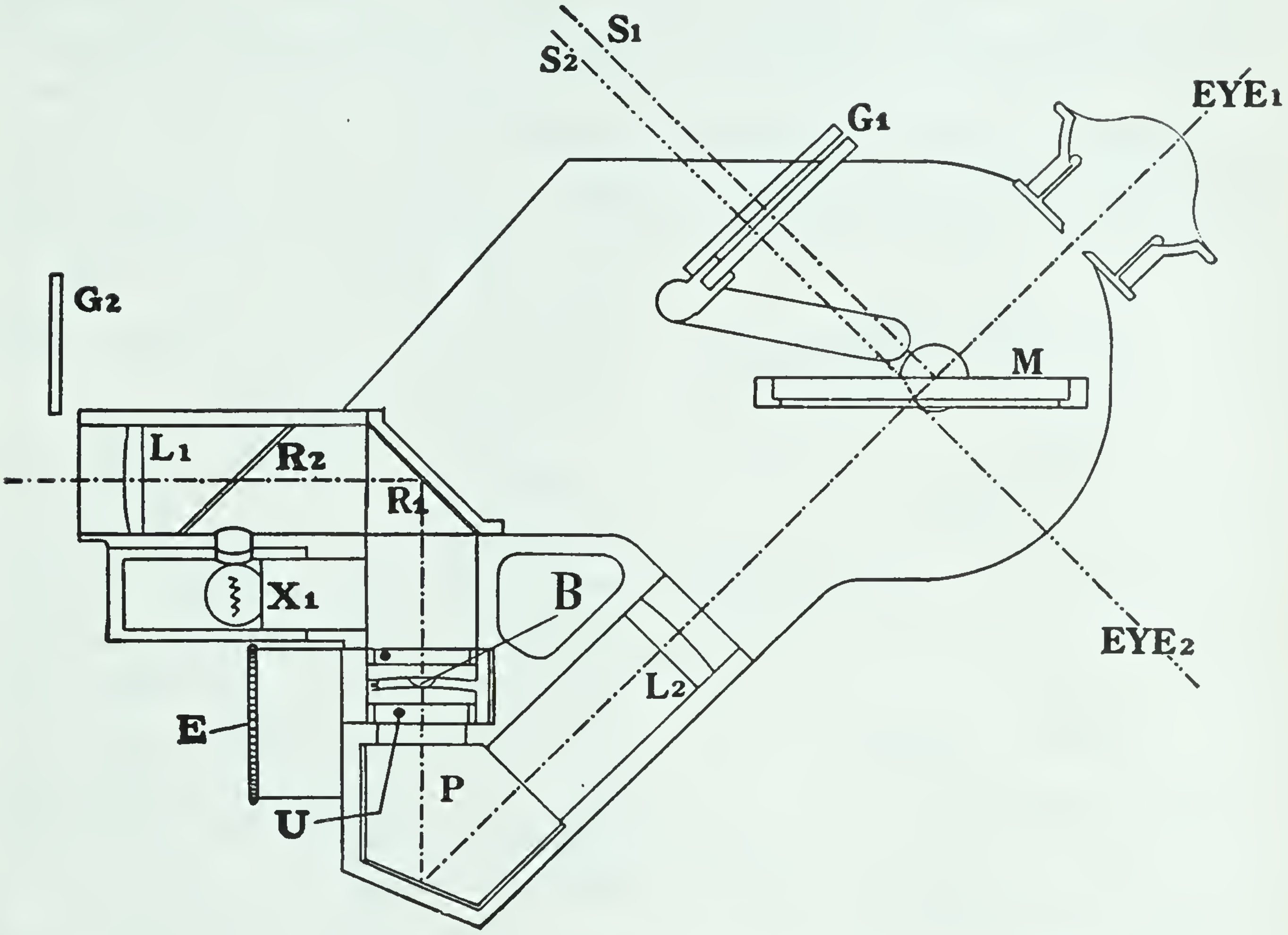


Fig. 327. A sextant

Figures 327 and 328 show the principal parts of a type of aircraft sextant commonly used.

The nautical sextant derives its name from the fact that angles



Bausch and Lomb Optical Company

Fig. 328. Diagram of an improved bubble sextant

are measured on a graduated arc which is one-sixth of a circle. In the bubble sextant this arc is replaced by a worm and gear mechanism operated by a knurled thumb wheel. The thumb wheel is placed so that it can be operated when the instrument is held before the eye for observation.

When the sun or moon is observed the moderating glass or glasses G_1 are put into position. There are two of these glasses. One of them reduces the brightness of the moon to a degree comfortable to the eye and both are used to reduce the brightness of the sun. Another sun filter G_2 may be dropped over the lens L_1. The bubble B is illuminated by throwing the toggle switch and adjusting the rheostat. A small flashlight battery is contained inside the right handle of the sextant. The eye is placed in the position Eye_1. Light from the bubble passes through the prism P and the lens L_2 through the index mirror M to Eye_1 which sees the bubble as if it were infinitely distant. Light from the sun or moon passes along the path S_1 through the moderating glasses G_1 to the index mirror M from which it is reflected also to Eye_1. The image of the sun or moon will coincide when the mirror M is at the correct angle of rotation. This rotation is accomplished by turning the knurled thumb wheel. When the images coincide the altitude may be read from the counter drums.

Identification of stars and planets. The aviator can identify major star groups. A known star must be observed if data are to be secured for plotting a line of position. For this reason it is essential for the navigator to be able to identify the more common stars and the visible planets.

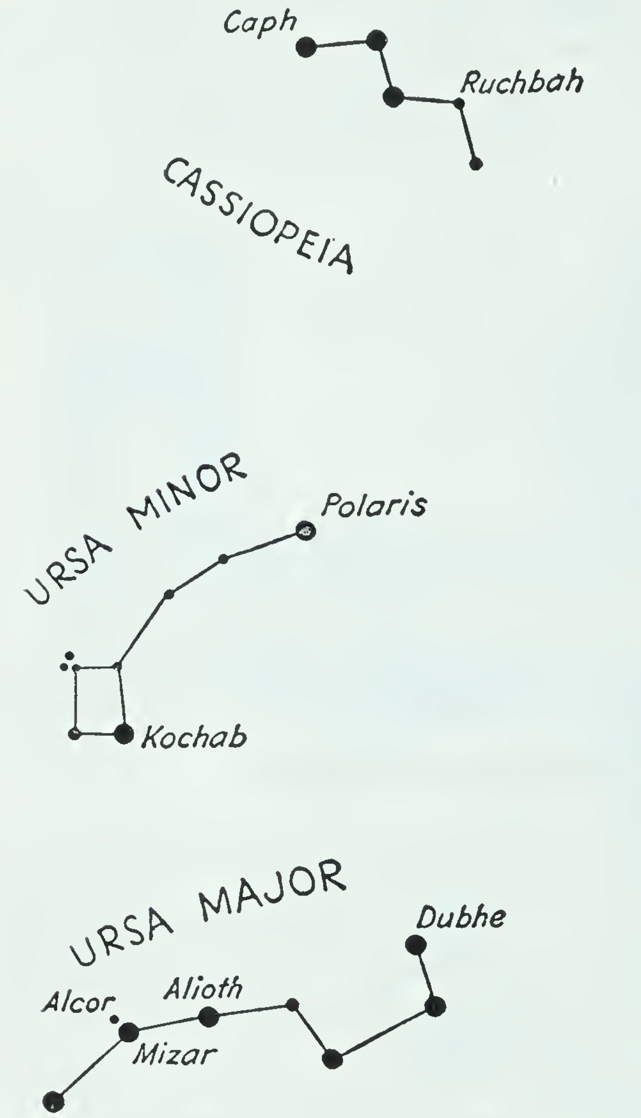


Fig. 329. Constellations near the North Star

Since January, 1941, the United States Naval Observatory has issued the *American Air Almanac* for use particularly in air navigation. This almanac lists fifty-five stars to which the aviator may refer. Probably the ability to recognize fifteen or twenty of the stars would be sufficient for usual navigational purposes.

A few stars such as Sirius and Vega possess distinctive characteristics and can be identified even if no other stars are visible. However, the usual method of identifying a star is to locate it within a known star group.

The star groups in the northern sky are distinctive and rather easily located. Probably the best known are the seven stars that make up the Big Dipper. Two of the stars in the Dipper are on a line with the North Star. They are commonly called the pointers because they help to locate the North Star. The distance to the North Star from the pointer nearer it looks to be about five times the distance between the pointers. A straight line from Alioth through Polaris leads to Cassiopeia.

Figure 329 is an illustration of the constellations around the North Star. Notice that one of the stars in the handle of the dipper has a companion star.

On the opposite side of the North Star from the Big Dipper is

Cassiopeia. Six of the stars in this constellation make a *W*. Some people think of this group as the woman in the chair.

The Little Dipper contains one of the most important stars in the sky. At the very end of the handle of the Little Dipper is the North Star.

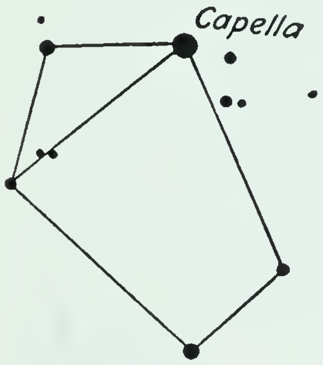


Fig. 330. Auriga

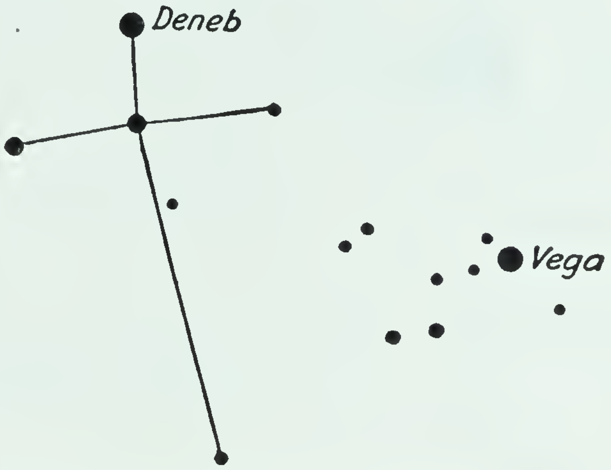


Fig. 331. Cygnus, the Northern Cross

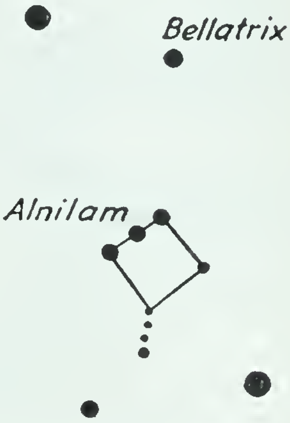


Fig. 332. Orion

In the winter the pentagon of Auriga rises in the northeast and sets in the northwest. Capella is the brightest star of this constellation. (Fig. 330.)

During the summer the Northern Cross is visible. It, too, rises in the northeast and crosses to the northwest. Nearby will be found Vega as shown in Figure 331.

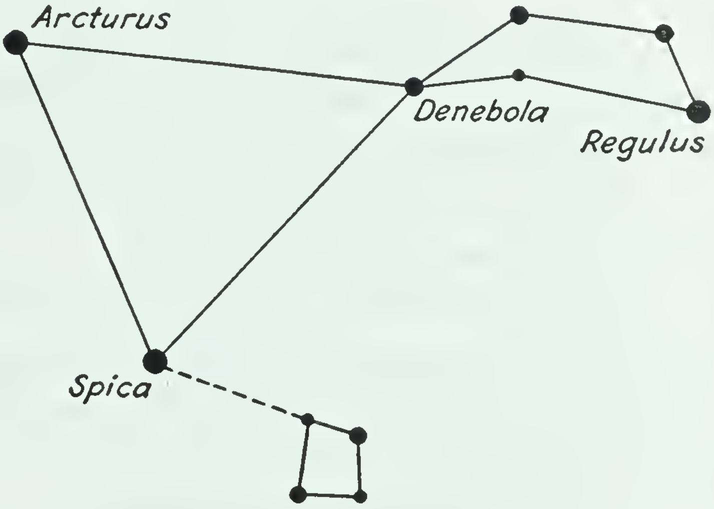


Fig. 333. Leo and Corvus

Farther from the north are three constellations which can be observed in turn during winter, spring, summer, and autumn. These are Orion, Leo and Corvus, Scorpio and Sagittarius, and the Square of Pegasus.

These constellations and the principal stars are shown in Figures 332, 333, 334, 335.

Laboratory Exercise 39. Observe the commoner constellations that are visible in your latitude. Make a second observation two weeks or four weeks later at the same hour and notice the change in position.

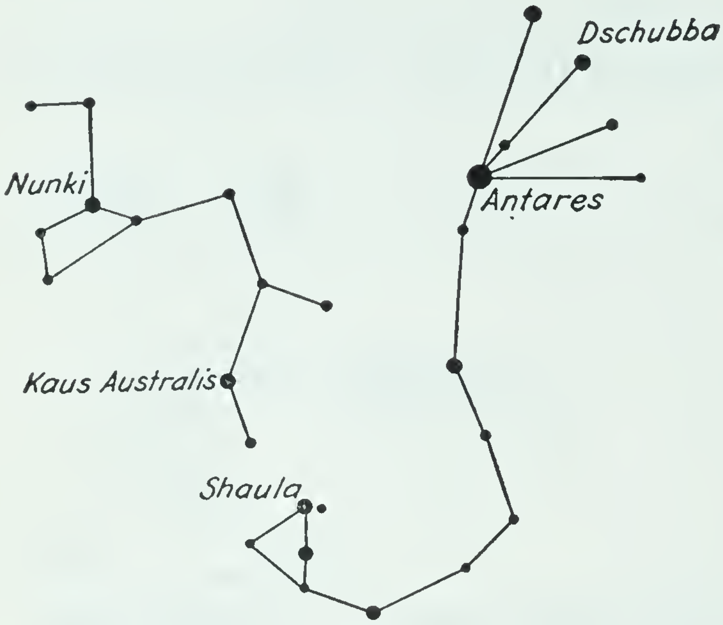


Fig. 334. Scorpio and Sagittarius

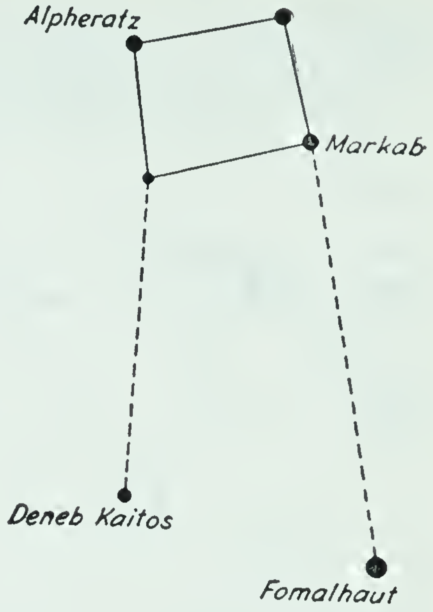


Fig. 335. Square of Pegasus

Application Activities

1. Plan a round-the-world flight. Locate on a world map the important cities to which you would fly, mark airports for refueling, and measure as accurately as you can the courses you would set.

2. Give a class report on an interesting book in which air navigation plays an important part.

3. In connection with your study of time, you may find it interesting to construct a sundial. Encyclopedia usually carry a brief description of how to make one. *Sundials* by Mayall and Mayall, published at Boston by Hale, Cushman, and Fling, provides specific suggestions for constructing sundials.

4. You may find it interesting to construct a simple sextant to measure the altitude of stars.

5. If you are near a radio-range station, perhaps you can pick up the signals on your radio. If possible, visit a radio-range station and observe how the signals are sent out.

6. Plan a trip from your nearest airport to some place you would like to visit. What is the course you would follow? How would you as pilot make use of the various methods of navigating?

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UNIT VII

How Workers Prepare for Aeronautical Jobs

Exploratory Activities

1. List as many jobs in aeronautics as you can.
2. Which of these jobs are the same or nearly the same as jobs in some other industry?
3. Do you know someone employed in aeronautics? How did he or she prepare for the job?
4. Are there workers in your community who could readily change to aeronautics jobs? What makes this change possible?
5. What things should a high school student consider in preparing for an aeronautics job?

Overview

A huge new industry has taken its place in the present-day world. It has grown at an astounding rate and its continued expansion is certain. Hundreds of thousands of persons already are engaged in manufacturing, flying, and servicing airplanes. Other thousands train pilots and technical workers, while the regulation and control of aviation engages an additional group. Another army of men and women are engaged in activities and industries related to aeronautics. In some way or other, men and women of nearly every level of ability and of every type of interest from the unskilled laborer to the research man, wherever they are located, will find the opportunity for participation in it. It is important that every informed citizen understand the immense influence which this new development is having and will continue to have on problems of employment.

This unit is of most value in understanding how aeronautics workers prepare for their jobs. It contains descriptions of various types of jobs in aeronautics and portrays, in part, employment opportunities in the field. This will be helpful in determining whether or not you would like to find employment in one or more of these jobs as well as helping you to learn about the work necessary to build and fly planes. Rigid job training may be necessary. For some jobs training is short and of a special kind; for other jobs training requires years. Certain personality characteristics and special aptitudes are required. These you either have or can develop to sufficient degree for some type of aeronautics job. You should learn how these qualities relate to high school work and experiences.

Problem 1. What are the kinds of jobs in the aeronautics industries?

The development of the aviation industry, like that of any other, will result in many social and occupational readjustments. The development of any great industry brings with it many far-reaching social changes. It may affect how a person will live, where he will live, and the kind of work he will do.

The growth of automobile transportation together with the development of automotive machinery, the building of roads suitable for use by automobiles and trucks, and the consequent establishment all over the country—not to say the world—of salesrooms, garages, and filling stations not only created an entirely new attitude towards travel; the activities also created thousands of different kinds of jobs for millions of persons over the whole land. At first only a few cars were made, and these were built largely by hand. As the demand for automobiles grew, machines were devised which would do the work of many men. All of this meant a readjustment of labor and with it a change in the lives of laborers' families with similar changes among employers and their families. Just as some men were thrown out of employment and found it difficult to make a living for themselves and their families, so some employers of labor saw their business disappear and the livelihood for their families endangered.

Large numbers of those who lost their work because of the passing of the "horse and buggy" age found new employment or new sources for investment in the automotive industry. In the total, directly and indirectly, technological employment has created more jobs than have been lost through technological unemployment, but there have been some jobs which could not be held by those who had been displaced from others—a harness maker might not become a good garage man—and even those persons who were absorbed into new industries have had to learn to do new things.

Now, as one considers the immense growth of air transportation, as he sees great airplane factories springing up in parts of the country in which there has hitherto been little of manufacturing, as he notes the airport in every sizeable town, and as he sees in many magazines and papers the advertisements of air schools, he is forced to ask what will be the effects of *this* new era in travel and transportation. Will there be more or fewer jobs? What kinds of work will be required in the new industry? Who will be able to do them? What will be the influence of this employment upon those who do not work directly in the aviation industry? These are questions of vital significance to high school pupils of the air age.

By this time the student has undoubtedly begun to ask himself what may be his place in this air age. Should he try to find work here connected with aeronautics? If so, what kind of work should he attempt to do? Is there a place for the special abilities which he seems to possess? The present unit will attempt an answer to some of these questions.

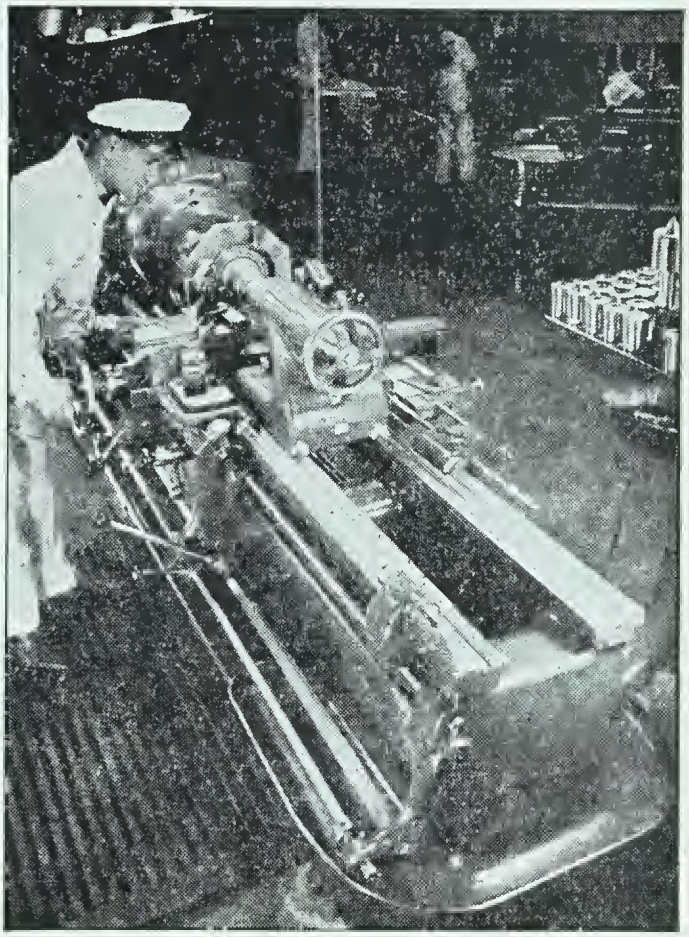
OPPORTUNITIES IN AVIATION

The field of aviation is large and offers a wide range of opportunities. There is no field today which offers a more exciting future or a greater variety of opportunities for a life's career than does aviation. It can be honestly stated that opportunity is knocking at the doors of many people who have a great variety of interests, aptitudes, and abilities. Careers are awaiting those who will get ready and will pay the price in work and effort.

A comparatively short time has elapsed since the first airplane flight; yet in that short time the industry has passed through its infancy and youth and is now entering its period of maturity. The airplane has not only brought the people of a nation closer together; it has made a neighborhood of the world. As this integration becomes closer, the network of air lanes will become as intricate as that of the railroads is today. This will mean that an enormous number of persons will become in one way or another associated with the industry.

Today, when aviation or aeronautics is mentioned or when a person is asked if he would like to enter the field, the tendency is to think of it, to visualize it, in terms of flying the plane. As in other industries, people tend to idolize the colorful, masterful figure at the controls. Many feel that they cannot meet the requirements for a pilot, and, therefore, that they cannot actively participate in aviation. That is far from the truth. Actually, many thousands of people will participate in aeronautics in other ways than in flying. It is true that a higher standard of performance is required in this than in most other industries—a much higher precision is reached in the manufacture of an airplane engine than in the manufacture of an automobile engine, for example. Nevertheless there will be found many chances to work for persons of nearly every type of ability.

The regular airlines running scheduled flights hire not only pilots and co-pilots, but a great number of other people, most of whom must have some amount of special training. To name some of them, we might include radio operators, dispatchers, meteorologists, operation managers, airplane and airplane-engine mechanics, traffic agents, radio engineers, instrument technicians and repair men, maintenance superintendents, and business executives. There is also work for airport engineers, airport managers, airport ground men and helpers. It is necessary for the airlines to employ clerks, typists, and stenographers as does any other big business. Other jobs in flying operations not connected with airlines include parachute riggers, instrument repair men, flying instructors, ground-school instructors, and aerial photographers, to name only a few. Still other opportunities in this field may come to salesmen or demonstrators of planes, or to such specialists in flying as those who "dust" crops to destroy insects, engage in forest-fire patrol, deliver supplies in emergencies, and the like. Obviously, many workers other



Courtesy United Air Lines

Fig. 336. In the aeronautics industry precision is the watchword. Tolerances can't be made too fine for aircraft engines. This expert has had years of experience in handling power tools, qualifying him for responsible tasks and the operation of modern precision machines like this variable speed lathe.

than those who actually go into the air or serve at airports are necessary.

Let us realize at the beginning that the airplane must be built. This brings to our attention a great manufacturing industry. First the plant must be built, involving laborers, carpenters, electricians, and engineers—to mention only a few. The plane that is to be manufactured must be designed and drawings of each part made. These blueprints or working drawings are made by draftsmen to be used by the skilled workers in the shop. Each of the several thousand parts of the airplane is carefully calculated as to size and materials.

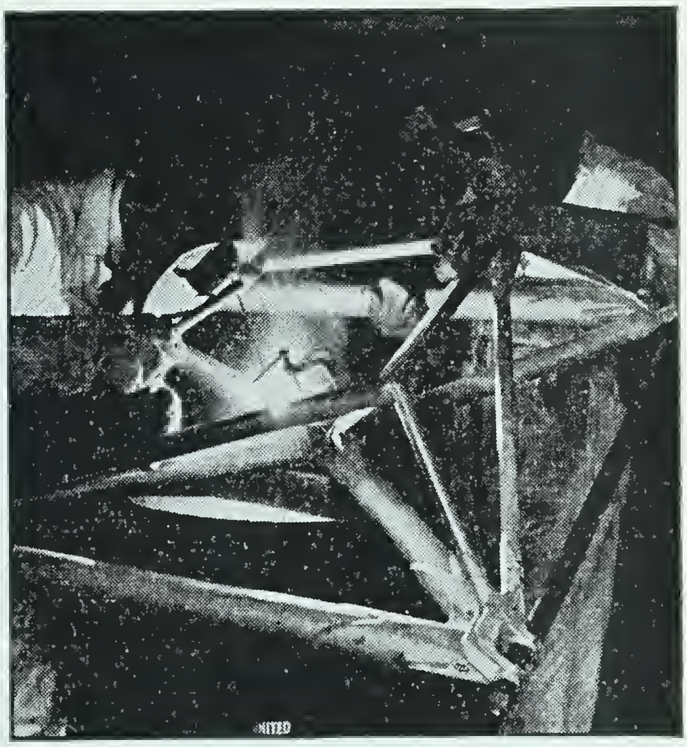
Courtesy United Air Lines

Fig. 337. A job in aeronautics which requires training in other fields is the dietitian's. Such jobs offer work to relatively few people, but their work is important in many fields.

Then there are positions in the area of aeronautics which require training in other fields rather than in any special aeronautics subject. Many people find work as writers, editors, librarians, dietitians, caterers, office workers, interior decorators, and publicity managers. As airmail grows in volume, and regular mail planes are put into service, post-office workers similar to those now on the railroad will also be employed. The fields of aviation medicine and aviation law are already being developed.

Jobs Connected with Aviation

Although all of the above-mentioned fields employ a considerable number of people, the greatest number of jobs in the aeronautics industry is represented by the field of manufacturing. This great field employs aeronautical engineers, test pilots, salesmen and demonstrators, draftsmen, executives, clerks, stenographers, and huge numbers of unskilled, semi-skilled, and skilled workers in the various trades such as welders, wood workers, sheet-metal workers, machinists, assembly men, and their helpers and apprentices. All told, many thousands of persons aid in manufacturing airplanes, airplane engines, and their accessories. While there has been concentration of such plants in a few parts of the country, the tendency now is to scatter them widely. The great majority of jobs available in such plants are commonplace. Many of them become very monotonous to people of certain temperaments. Such jobs may be on a production line, where each individual does the same kind of work day by day and week by week. There is much less than formerly of individual handwork in the manufacture of planes. With the discovery and development of an improved type of riveting, with the discovery of the spot-welding process on the new alloys used in making aircraft, and with mass production, the general types of things done in an aircraft plant changed almost overnight. Metals are now used far more than formerly. Metal tubes, metal wires, metal cables, or sheets of metal are used in almost every department. Much of the metal is aluminum or magnesium-aluminum alloy which, being light, can be

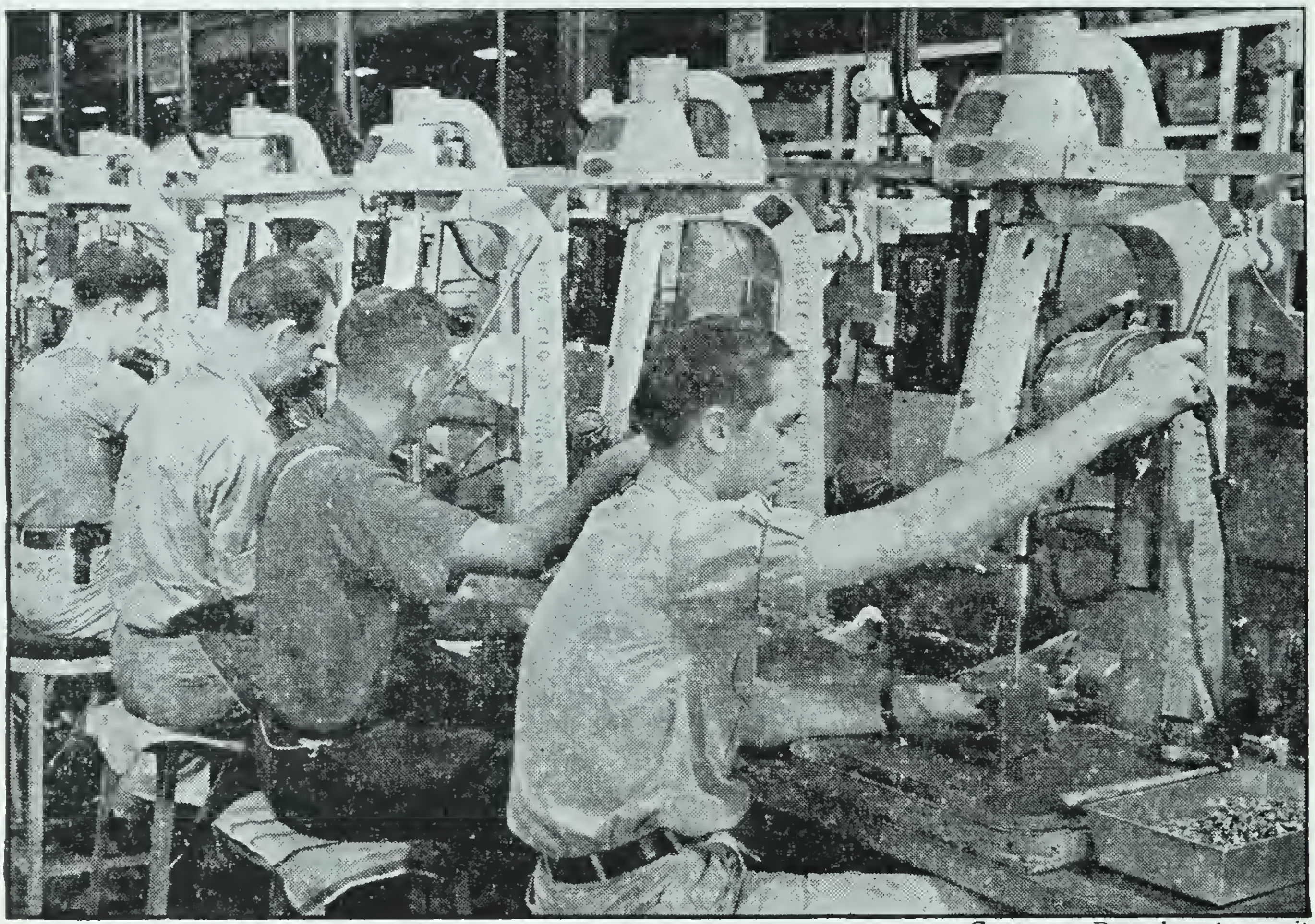


Courtesy United Air Lines

Fig. 338. Experts in electric arc and oxyacetylene welding are essential in aircraft manufacture.

handled by women. These alloys are new metals developed in the chemical laboratory by a special type of chemist known as a *metallurgist.*

Persons in these plants use all kinds of machines, such as stamping machines, lathes, grinders, buffers, polishers, borers, punches, shapers, and sanders. Most plants are divided into sections or units in each of which groups of men and women work on one part of a plane. One group, for example, may work on the fuselage; another may be working entirely on the assembly of lubrication units; others, on landing gears; others, on wings, or maybe just on gasoline tanks.



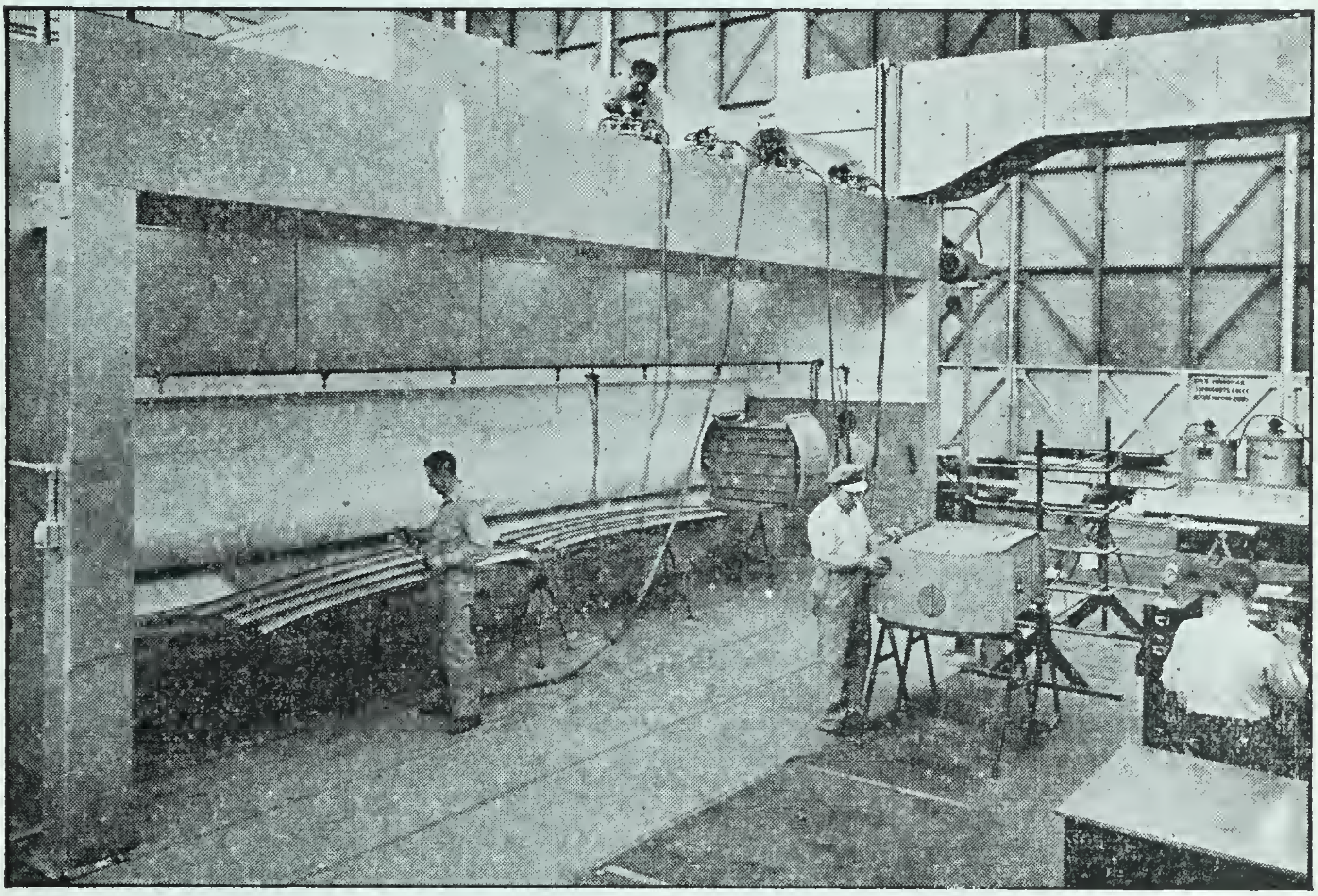
Courtesy Douglas Aircraft

Fig. 339. Mass production. These jobs are very necessary and furnish work for many people. They require accuracy and speed, but may be monotonous for some people.

There are also groups or sections which work with brakes, or the assembly of the hydraulic units used for lowering and raising the landing gears. Others work with the plastic materials which are molded and shaped by heating processes and with big presses which shape the noses of the plane and the window frames. All the large manufacturing plants maintain tool departments, whose sole job is to keep the tools throughout the plant in the best working condition.

In an aircraft plant, there will be no job which is not completely covered by careful inspection and tested several times. From the tiniest parts to entirely assembled wings or fuselages, inspectors check thoroughly. It is not uncommon to have an inspector for the work of as few as ten workers.

The beginner in machine operation starts with those machines that are more or less easy to operate, and which are largely automatic. Jobs with these machines are, of course, the type which pay the lowest wages. The person operating machines should take advantage of any opportunity offered to learn other machines, and plan to work ultimately with the precision machines and lathes, for which work somewhat higher wages are paid. Many an operator starts in with a job as an apprentice, and after experience has proved his ability, looks forward to advancing to the position of what is called a *lead man.* The lead man has under him anywhere from six to twelve workers. He may look forward to advancing to the rank of a sub-foreman who will have, in turn, several lead men responsible to him. The sub-foreman will look forward to a job as foreman, and the foreman to

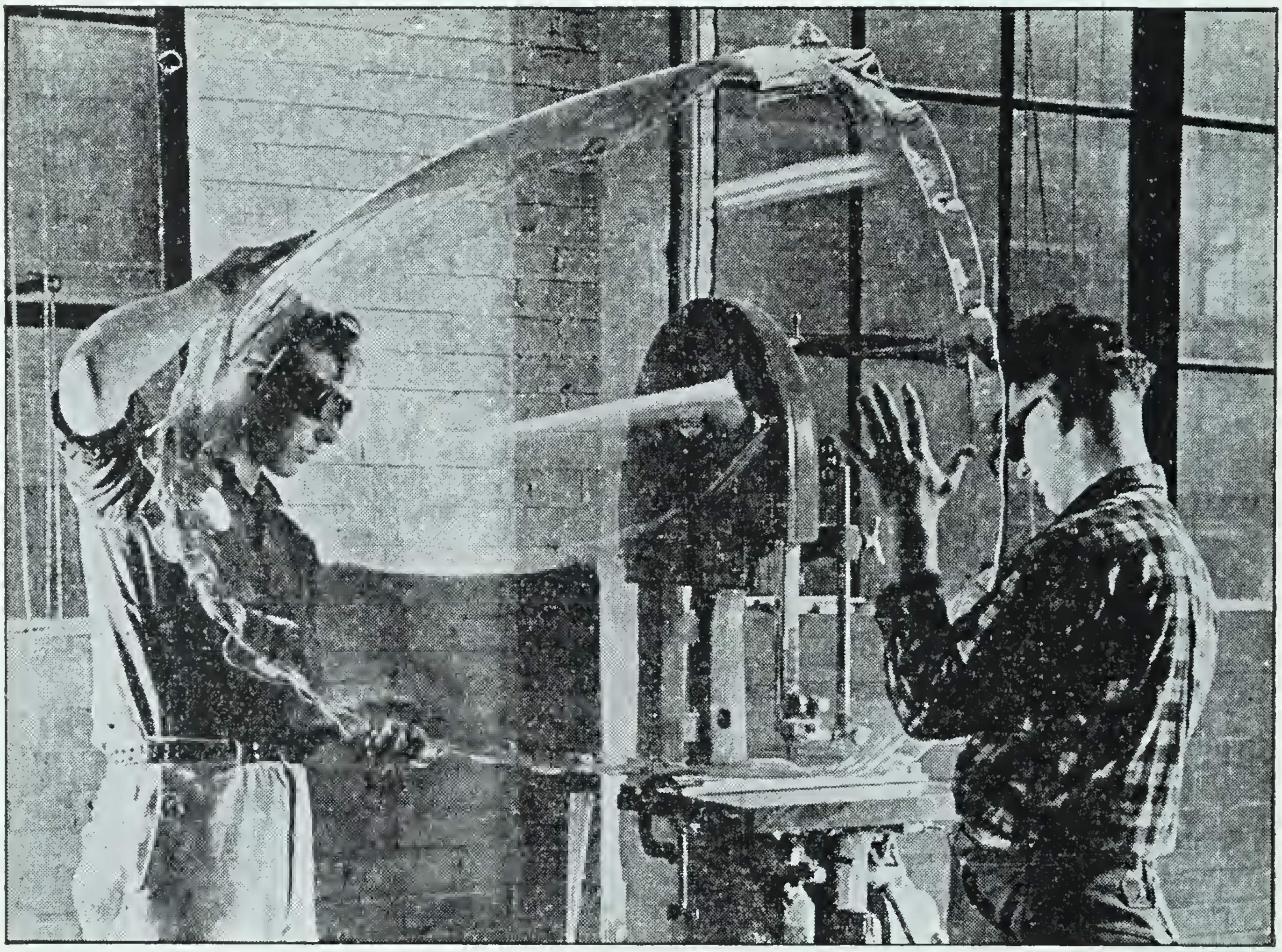


Courtesy Consolidated Aircraft Corporation

Fig. 340. Painters are used in many jobs in aircraft production. These men are painting the gas tanks for a large transport plane.

the job of department head. Some department heads may become plant superintendents and finally may attain a high executive office.

Plants which produce the small and common types of two- to six-passenger planes sold to private individuals, utilize handwork of a high quality. This business involves work with wood and with cloth which are used in the construction of the fuselage, for covering of the wings, and tail assemblies, plus the processes of treating this wood and cloth. At the present time training planes have much of this type of construction, but aside from these, there is a comparatively small amount of this type of work left to the industry, and what its future will be is very uncertain.



Courtesy Rohm and Haas Company

Fig. 341. Workmen cutting a rough form of a new plastic to form the transparent nose section for a large plane. Research chemists developed this plastic, which is half as heavy as glass and far more malleable. It can be worked with ordinary tools, and though not bullet proof, it is shatter proof and is made from coal and air.

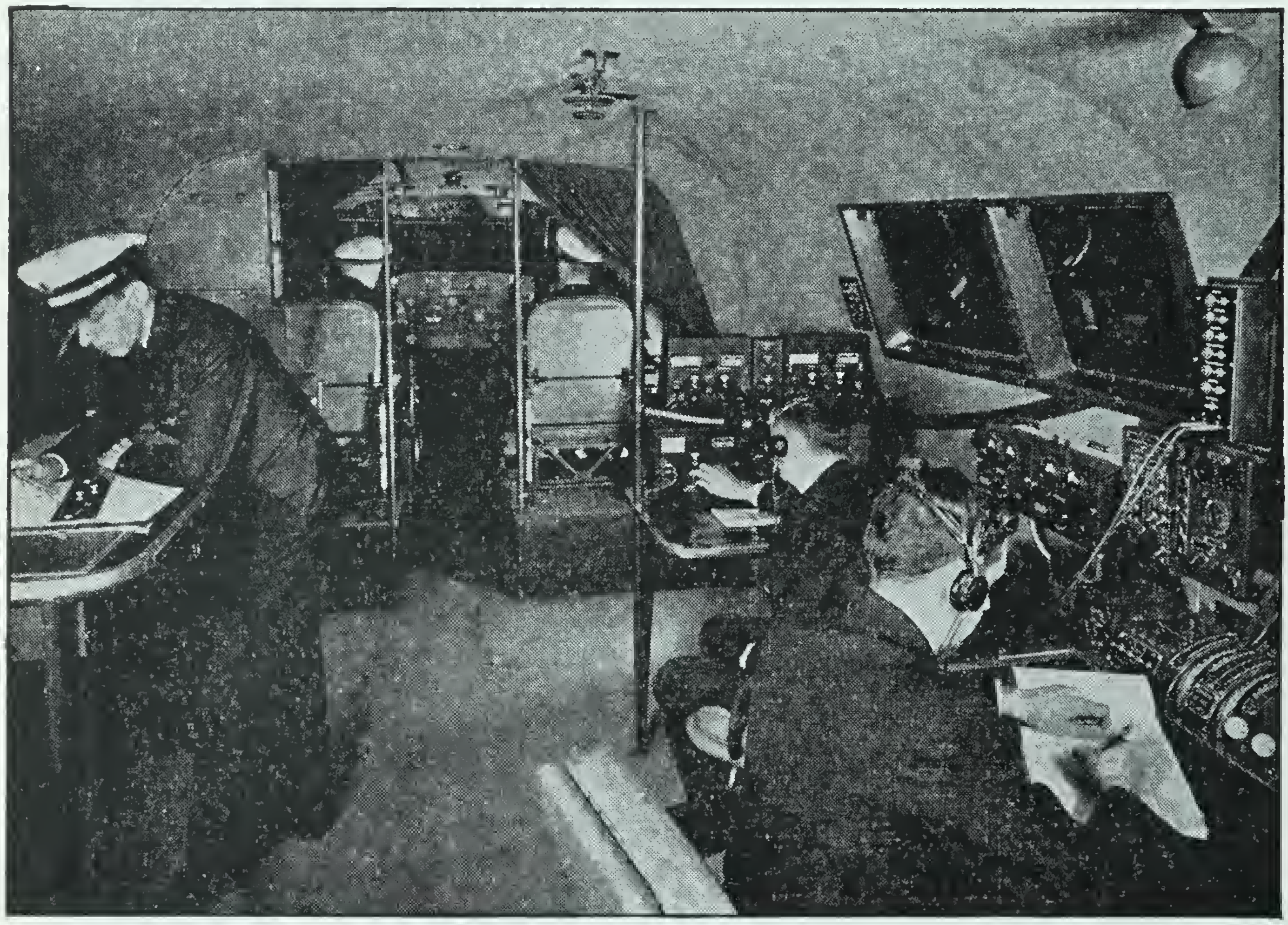
If the main plant does not make all of the parts, they must be bought from some other factory. Each of these factories of course employs its own force. There are hundreds of these factories today producing parts and materials for making airplanes. These plants are scattered throughout the United States. There are countless other plants whose chief business is in a field not directly related to aircraft production, but whose product finds some use in the building of a plane or in some branch of the aeronautics field. Examples of such plants are those which manufacture uniforms or parachutes, or which print time tables, or which produce cement for runways.

Another agency in the field of aeronautics is the Civil Aeronautics Administration, with headquarters in Washington, D. C. The Civil Aeronautics Administration employs in its central and field organization over 8000 people. Many of these persons are holding jobs or positions which are not ordinarily open to beginners in the work. Rather, they are held by men of training and experience who have grown up with aviation. While these jobs are not for the beginner, they are jobs to which the beginner may aspire or look to for promotion. In addition to many jobs mentioned above in connection with other fields, such as those of pilots, engineers, radio technicians, and executives, the Civil Aeronautics Administration employs a great number of inspectors who are specialists in construction, in airport design, and in equipment.

There are thousands of people today who ask where and how one can get into aviation work. There is no short, simple answer to this question. First, it will probably be interesting to look at a few of the particular jobs in each of the great areas of work. Some kinds of jobs, such as those of pilots, are open to comparatively few people. This is also true of the engineering positions, as well as those of the executive and administrative types. Other branches of the aeronautics field employ great numbers of people. These may be exemplified by the positions of clerk, typist, stenographer, and factory worker in all types of manufacturing plants. As is usual throughout industry, the years of training and experience required for a job are in inverse proportion to the number of people employed in that work. That is, those jobs requiring technical training and long experience employ relatively fewer people than those requiring little or no training or experience of a special kind. Almost no job can be obtained at an age below seventeen or eighteen.

Although there are not many pilots in comparison with the total number of persons in the aviation industry, the pilot does represent, in a sense, the apex of the whole structure. Individually, too, the airlines pilot or the pilot of military planes is the most highly selected member of the entire personnel. An increasingly large number of private or commercial pilots for whom the standards are somewhat lower is being trained. This field will always utilize a large number of pilots.

On the big planes there is usually, in addition to the pilot, a co-pilot who must have all of the qualifications of a pilot except that he may have fewer hours of flying experience; a radio engineer; and a navigator. As a rule the pilot and co-pilot must be able to operate the radio, and the radio operator or navigator must be a qualified pilot. In fact many radio men and flight engineers or navigators were formerly pilots who are now overage or otherwise disqualified for active service as pilots. A man flying his own plane must obviously need to combine, to some degree, the qualifications of all members of a crew. This is true to a larger extent than in driving a car, for if something goes wrong he cannot merely draw up to the side of the road until a truck driver or a highway patrolman comes along.



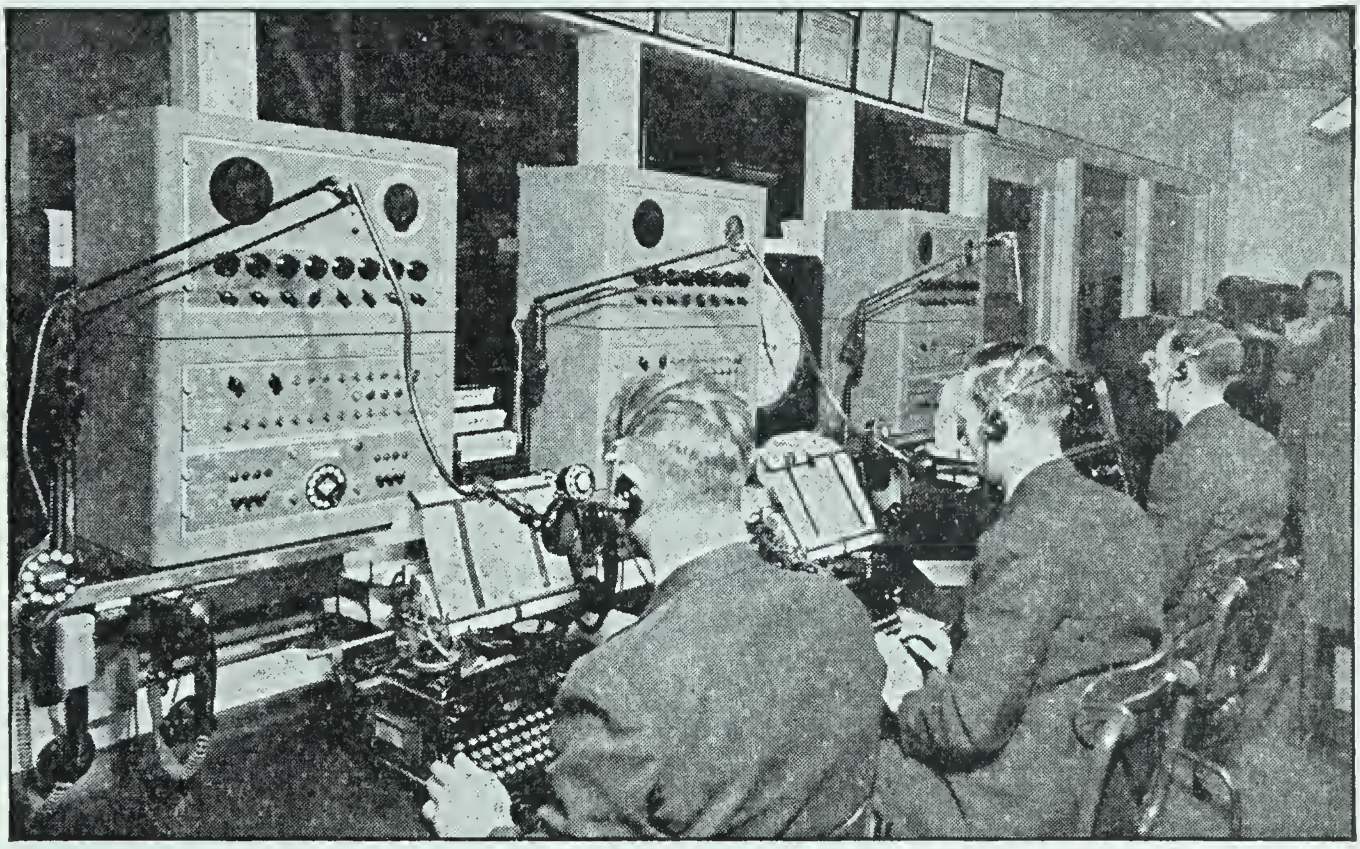
Courtesy Pan American Airways

Fig. 342. This transoceanic clipper carries a crew made up of a pilot, co-pilot, navigator, radio engineer, flight engineer, and a steward or stewardess. The flight engineer keeps constant check of the engines by use of instruments on the panel at the right.

The transport planes, too, carry a steward or stewardess, most of them the latter. On most lines a stewardess must be a graduate nurse—although recently this requirement was dropped, at least temporarily.

To show the range of abilities needed for competency in certain jobs, a few have been selected for more detailed description, those chosen being some about which the average reader is not especially well informed.

One of the jobs which interest many high-school students is that of radio operator for an airline. It is a most exacting job and requires undivided attention while on duty. The operator must communicate with the plane while in flight. Pilots report by prearranged time schedules, and ground men must be ready to take the message, which is terse, precise, and to the point. Arrangements are made whereby during the last ten seconds of every minute there is a dead silence on the frequency being used in order that in emergency it is possible for a pilot to cut in without interference from others. To be proficient and accurate in this work, the radio man must be able to spell and to pronounce correctly the names of all the personnel and of all places or points on the route of the division in which he works. He must know all the facilities of that division, such as emergency

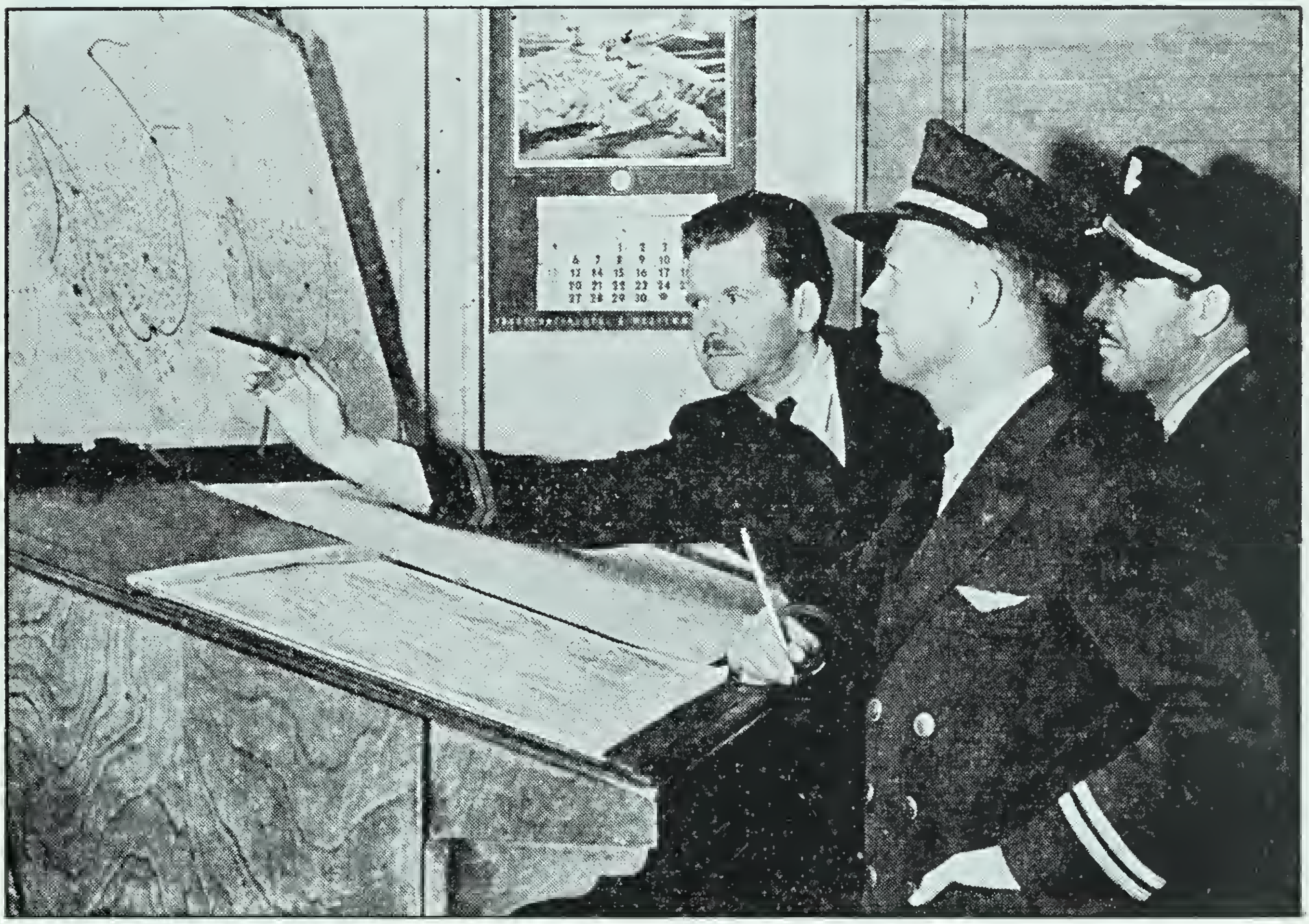


Courtesy United Air Lines

Fig. 343. The voice of the airways. Planes flying at high speeds and high altitudes are never out of touch with the ground, thanks to radio. Two-way radio-telephone communication is maintained between this ground station and planes. Notice licenses above the equipment.

landing fields, beacon lights, fuel and repair shops, hotels which can be used, bus and train schedules and connections, so that if the weather ahead makes it necessary in the interest of safety to ground a plane, the passengers will be aided as much as possible and made comfortable. He must be thoroughly familiar with teletype symbols and abbreviations which are used in the weather service. He must be able to operate the teletype machine. He must have a good command of the English language and be able to enunciate clearly and rapidly. He must be able to write rapidly and legibly. He must be able to think and act quickly. Truly, he must be a clock watcher, as all operations go to the second, and if he is not ready and able to take the message accurately, dire results may occur. He must have the ability to keep the radio equipment in good operating condition. If he happens to be located in an intermediate or local airport, he may have added to these duties such things as running a local weather information bureau. Under these conditions, he will report both to pilots and to other stations in his division the barometric pressure, the temperature, the ceiling, visibility, and wind direction and velocity. He may also be called upon to help load and service planes which land at his station. He often cares for other station routine, helping to keep the records and to answer correspondence. At times, he may act as the field traffic manager, selling the tickets, handling the express, and even making talks to civic organizations and groups. He may be stationed where it is extremely important that he be able immediately to detect trouble with his equipment and then be able to repair it as quickly as possible. This, of course, makes necessary a knowledge of the theory and mechanics of radio. Some of the airlines take young, inexperienced men and train them; others require at least a third-class or, even better, a second-class radio-telephone license before they will put them on their payroll and give them the necessary additional training and apprentice experience. Some airlines say the radio operator need not know code, but others, especially those operating outside the continental United States, definitely require that knowledge. Certainly anyone planning a career of this type should know or be able to learn code.

Perhaps a person would like to be a weather man. To forecast the weather, he will need to become a meteorologist, and this occupation cannot be learned in a day. It is scientific work and highly important to all airlines. One qualifying for this type of work must have training and education above that of the high school. It would be well if the high-school training to prepare for it included such subjects as mathematics and physics. The weather man for any branch of aeronautics, whether with an airline or otherwise, has several important duties. He has to collect weather data from all possible sources. This includes recording reports from the hundreds of local weather stations that are scattered all over the continental United States, as well as from some more distant places, and from ships at sea. When all these data have been collected, the weather man plots them on maps, so that he can get a picture of the weather conditions over the whole territory. After he has plotted the data and obtained the picture, he then makes a forecast and a report on the flying conditions for the use of pilots. It is on his recommendation that dispatchers at airports will release the scheduled or special flights. This means that the weather forecaster must be a man of much training and long experience. He must be dependable and steady, for his recommendation to the dispatcher in releasing a flight may be a decision which will involve the lives or safety of many people. In his conference with

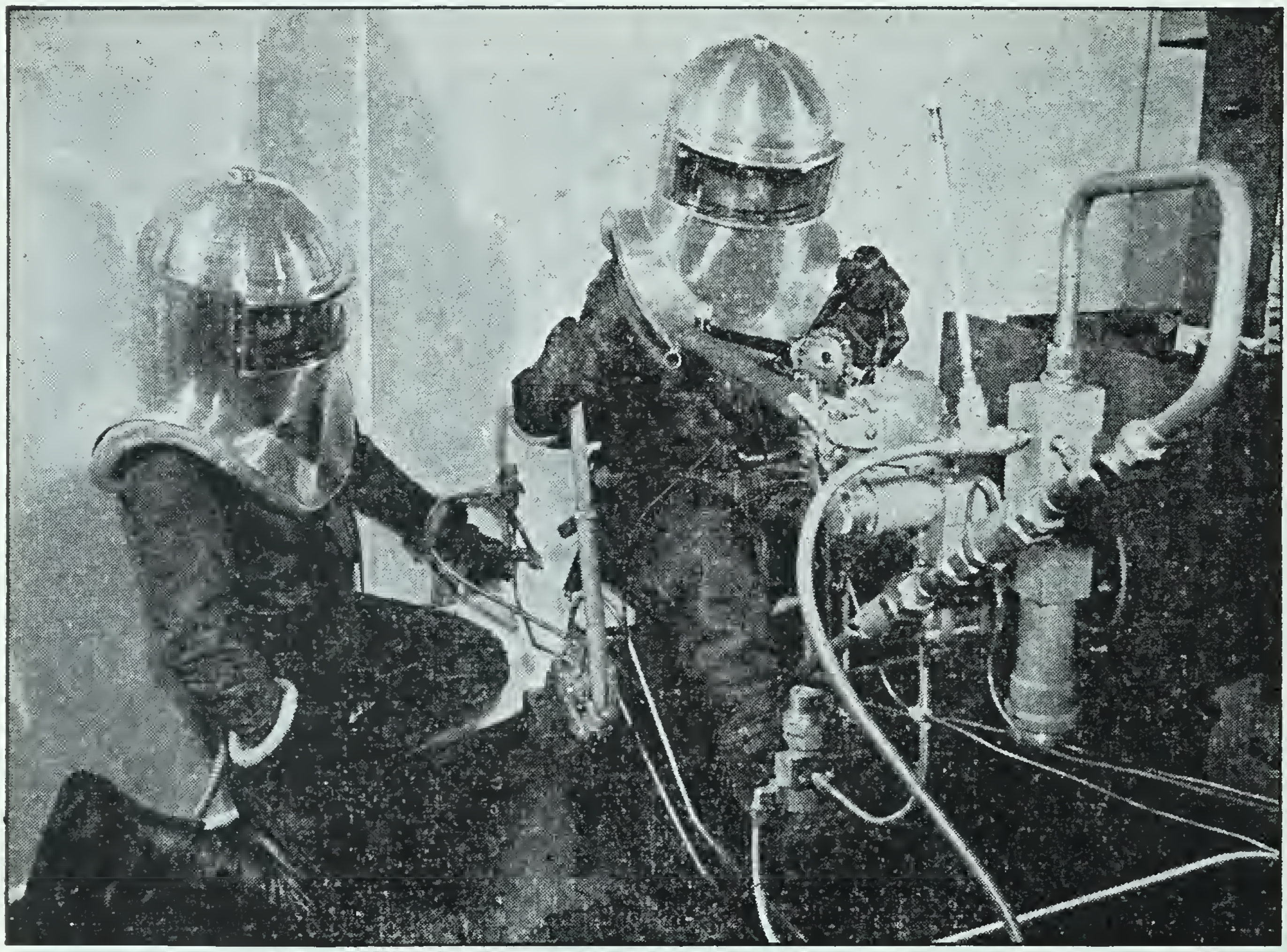


Courtesy Transcontinental and Western Air, Inc.

Fig. 344. Dispatcher explaining weather conditions which the captain and first officer will encounter on their flight

the pilot before each flight, he will advise at what level to fly in order to get most favorable winds; he will give information on barometric pressure, visibility, ceiling, and precipitation. The longer the distance of flights, the more vital becomes the work of the weather man.

A well-trained engineer will find many places for his talent in the aeronautics industry. If his interest leads him to the desire to work in an engine-manufacturing plant, he may work on problems of building engines; on improvements to produce better or more efficient engines; as an accessory engineer, working to make better carburetors, starters, generators, or superchargers; or as an instrument engineer, who seeks to improve instruments which tell the operator how the engine is performing. Also available in the manufacturing plant are jobs as metallurgical engineers who must have training in chemistry, or as communication or production engineers. All these division engineers will often work under a *project engineer* who

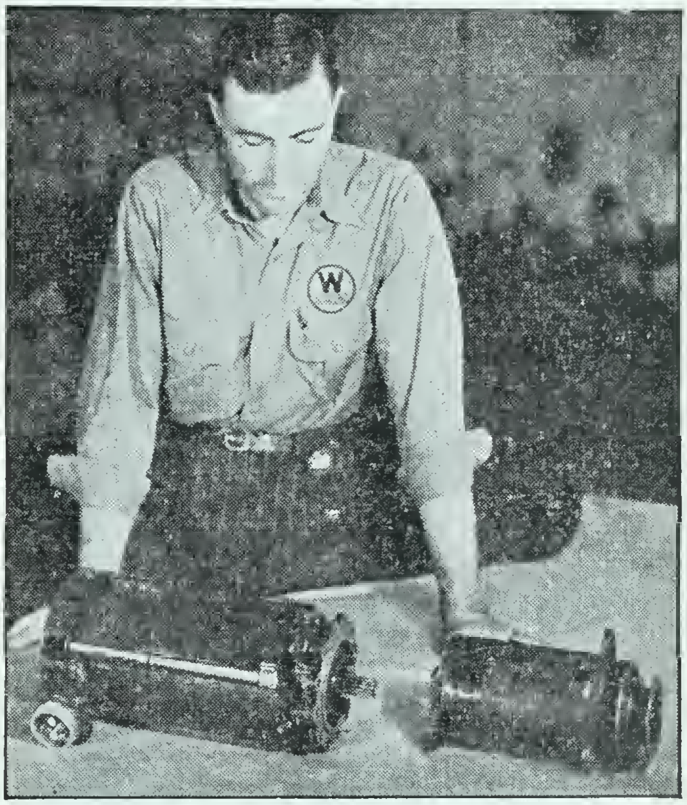


Courtesy Douglas Aircraft

Fig. 345. Finding the answers. Research is necessary to progress. In rooms like this, high altitude conditions are reproduced to study the effects of low temperature and pressure on men and machines. Engineers are in charge of all types of research.

supervises an entire unit of engineers doing tasks as described above. These project engineers naturally are responsible to a chief engineer or to an engineer who is in charge of all engineering projects of any given plant. Civil engineers are employed also in airport construction and airport operations. A few engineers find opportunities as insurance consultants.

There are places in aviation for those who are not particularly interested in the subjects of mathematics and the sciences. For example there is the traffic clerk. This person is likely to be employed only by the larger airlines of the nation, although a few find employment at independent, municipal, or private airports. His job is handling the passengers. He reserves places on planes, sells the tickets, and helps the passenger plan a trip, aiding with information on connecting airlines, as well as advising about bus and train schedules. He serves as an information bureau for the public, answering all kinds of questions about travel by air, about weather, about baggage regulations, or even about how it feels to fly. He must sell air travel, and on his airline if possible. The traffic clerk must have the passenger's name and address, so that he may be reached if a flight is canceled. His weight must be known, because the total weight load of the plane is checked. If the office is downtown rather than at the airport, the bus or taxi which delivers the passengers to the airport must leave in time to get them there, so that the baggage can be checked and loaded before take-off time. If a flight is not completed and a plane is grounded, the clerk at the airport of that depot makes hotel arrangements, gets train accommodations if possible or necessary, and takes complete charge of the passengers, making them as comfortable and happy as possible



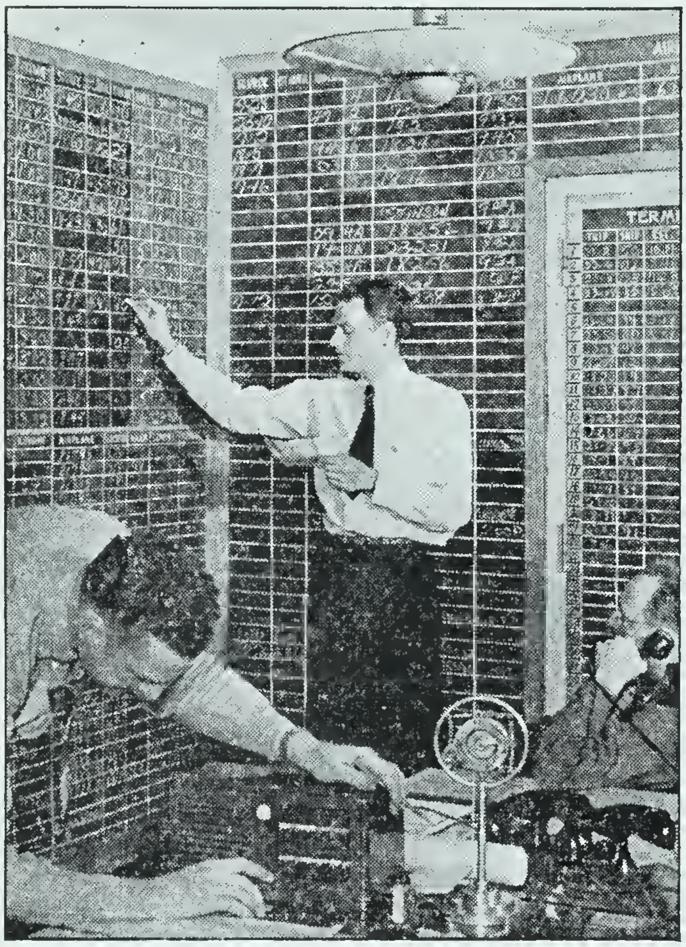
Courtesy Westinghouse Electric and Manufacturing Company

Fig. 346. Research supplies a need. Airplanes today require high-power, lightweight generators. The generator on the left has 35 times greater output and is not more than twice the size or weight of the standard automobile unit at the right.

under the circumstances. In the large cities it is possible to divide these duties so that the various jobs are more specialized.

In aviation, persons are needed also whose training is in nearly every aspect of business. The purchasing of materials, the arranging for trade routes, the drawing of contracts, the settling of claims and of disputes, the writing of insurance, the forecasting of population trends and of trends in economic development are but a few of the phases of business which are a part of the aviation industry. The large companies, too, have an increasingly large number of foreign representatives who need to be acquainted with the geography, the industries, the language, and frequently the politics of the countries in which they are stationed.

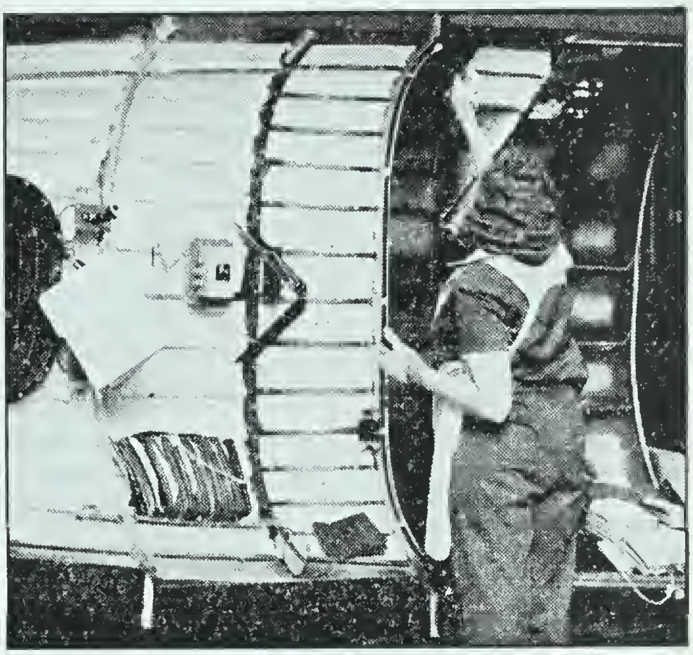
Many of the people now being taken into work directly or indirectly connected with aviation might have been excluded from the industry under normal expansion conditions because of their lack of training and experience. Necessity has made their employment imperative. It is difficult to foretell what will happen in the future. However, those who have turned out to be the better workers and the better trained will probably survive the readjustment and hold their jobs through the post-war period, whereas the less skilled and poorly trained will be eliminated.



Courtesy American Airlines

Fig. 347. These workers keep the location and condition of every plane in an airline fleet. No plane flies over the allotted time, yet coordination makes it possible for a line to meet all schedules with perfectly conditioned equipment.

Until recently only a few women were employed in the aviation industry, and most of these were stenographers, secretaries, or hostesses. A few, indeed, have been commercial pilots, flying instructors, airport operators, and managers. Some have found places as personnel workers, air-travel advisers, and interior decorators. Largely as a result of the war emergency, many factories are using women for many of the actual manufacturing processes. There are very few processes which are not now being done by women. Some are even driving trucks. In many jobs women excel men. This seems to be especially true of those jobs in assembly lines and the like, which are to many men irksome or monotonous. Women make good welders and splendid inspectors. Techniques have been devised too, by which some of the jobs formerly thought to be too heavy even for men are now being successfully filled by women of only mediocre strength. It has been estimated that within a few months more than 100,000 women will be employed in the manufacture of aircraft. In some manufacturing plants they already constitute fifty per cent of the personnel. Although up to date few women are employed in jobs involving actual flying, it is not at all unlikely that larger numbers will even become pilots. Several aircraft plant managers now insist that the place of women in the industry is permanently established and is not merely a war expedient. So aeronautics can no longer be said to be limited to the world of men.



Courtesy Consolidated Aircraft Corporation

Fig. 348. Women have earned a place in the production of aircraft. This employee installs insulation for the cabin of a large plane.

It is apparent that the effect of the aviation industry upon employment will be enormous. The influence will be felt by nearly everyone in whatever part of the world he lives. Products of the farms are being used in building aircraft; new metals have been developed; new problems have arisen for teachers, lawyers, physicians, and scientists. In the air age there is work for any man or woman whether he be unskilled, semi-skilled, or skilled labor; for the technician, the scientist, the stenographer, the businessman. If a person wants to fly or if he prefers to stay on the ground; if he likes to work in a factory or if he prefers employment in an office, if he has a desire to go to foreign countries or prefers to stay at home, whatever, in a word, may be his abilities or his interests, he can find a profitable and an enjoyable vocation in aeronautics.

Exercise 1. Arrange for the class to visit a local airport and, if possible, a manufacturing concern that makes materials used in airplanes or used by airlines. The class should observe various employees and the things they do in their respective jobs. Be sure to notice office, sales, research, or similar employees in addition to those that work directly with the planes. Organize a committee of the class to interview the employment officer to obtain lists of jobs in his plant. Have the class classify these jobs according to their types such as maintenance, office, manufacturing, sales, and the like. Keep this classification for use in Problem 3.

Exercise 2. (Alternative for Ex. 1.) Have a member of the class obtain the following: (*a*) regional office address of the nearest operating airline; (*b*) the address of one or more aircraft manufacturers from advertisements in current magazines; (*c*) location of the nearest United States Employment agency. Organize committees of the class to write each of the above for information regarding kinds of jobs available in aeronautics or airplane manufacture. All information should be presented to the class and jobs listed according to the classifications mentioned in Exercise 1. Keep the classification for use in Problem 3.

Courtesy Douglas Aircraft

Fig. 349. Women are employed to operate precision machines. This accurate instrument is used to make final checks on aircraft parts. This worker checks dimensions. Her job requires great accuracy and dependability.

Exercise 3. Prepare a list of new developments in aeronautics that are taking place now. Information can be obtained from articles and advertisements in magazines and newspapers, and from radio programs. Individuals in the community may be of assistance in determining how ordinary business and professional workers are being influenced by developments in aeronautics.

Exercise 4. Organize a committee to work with the school librarian in the preparation of a list of books that describe aeronautics jobs. Arrange for some member of the committee or class to discuss the more interesting books with the entire class.

Problem 2. What are the advantages and disadvantages of aeronautics jobs?

Regardless of the industry or profession one selects for his career, he will find there are desirable and undesirable features about it. The best job in the world will have some things about it which are not ideal.

An advantage in obtaining a job in aviation is that the industry will almost certainly continue to grow. The rate of growth after the present world conflict may be uncertain, but no one doubts that it will grow. There may be, after the war, a temporary reduction in employees in the manufacturing plants because of the need of adjustment and retooling. There is little likelihood of reduction in flying and maintenance services, but, rather, continued expansion is almost certain. When more labor is available and there is, consequently, increased competition for jobs, those with the best work records will be the ones who are retained, and those with the best preparation will be employed. In any event it is probable that in aviation one will find one of the best opportunities for work.

One of the things often considered in the selection of a career is the attitude the general public takes toward the work. An advantage in selecting a career in aviation is that the men working in the field are in general of a very fine type. Because of the rigid requirements of the work in all its branches from the executive down to the airport helper, the best type of person in each kind of work has been selected. This selection has resulted in an aggressive, far-sighted, intelligent, and able group of workers. As more people find work in the field, this high regard may be somewhat lessened, but it is altogether probable that in prestige aviation will continue to rank among the "best" jobs.

With respect to salary and wages it should be recalled that income should be considered in the light of the geographical location of the work, whether or not the job is in a large population center where living costs tend to be high, whether one has to commute to his work, and so on. There are instances where a salary of $2,100 per year has forced a family to a lower standard of living than they could enjoy on their former salary of $1,500 per year in another location. There is an old saying which might apply here: "It's the margin between what you make and what it costs to live which constitutes your real salary." In general, it is true that when wages are high so is the cost of living. Up to the present time, the rate of pay in the aviation industry has compared favorably with that of other industries. There are some types of work, too, in which the men in aviation receive higher pay than do men in similar work elsewhere. One notable example is the mechanic. Aviation mechanics holding an aircraft or engine rating receive higher wages than do automobile mechanics, but the requirements needed to obtain the jobs are also higher.

Courtesy United Air Lines

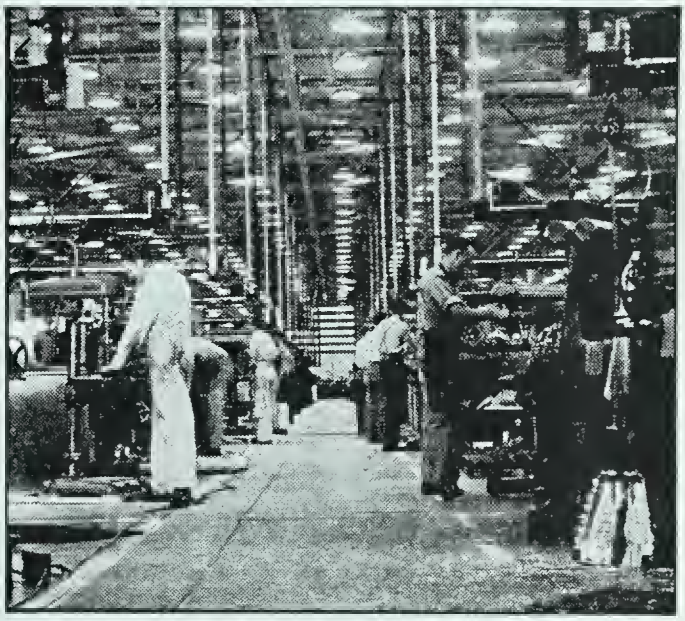
Fig. 350. Pleasant, healthful working conditions make many jobs desirable. Traffic agents and clerks represent the airline to the public. Notice the interior decoration in this office.

Airline pilots, too, receive good pay, higher than does the railroad engineer, but again the qualifications for the pilot are higher. Salaries for airline pilots range from $600 or $700 to $1000 per month, and co-pilots receive from $250 to $500 per month.

Because of recent large population increases in centers where the manufacturing plants are located, it is sometimes necessary to live in rather cramped and otherwise undesirable quarters. An employee of an airport may have to live several miles from his work—with consequent transportation cost; or it may be necessary to live in a part of the city that is not wholly desirable. It is well to recognize these situations in order to estimate the real worth of a job. In respect to living conditions, however, aviation will compare favorably with the other similar industries. The standard of living is, to a large extent, in direct proportion to income. If the job is one in which work in aviation pays a salary higher than that of comparable work elsewhere, a proportionally higher standard of living may be enjoyed.

There are a few jobs in aeronautics, for example in the field of meteorology, where it may be necessary, for a time at least, to live in isolated places such as lonely outposts on islands or isolated mountain stations. These conditions may make impossible normal family life for a considerable period of time. To many single men they have great appeal.

The health hazards of a job are also important. Such hazards in aeronautics are no greater than in other similar industries; indeed they are probably considerably less, for most of the plants in the aircraft industry are new and modern, and therefore have the latest type tools and equipment and are provided with the very best safety devices. The plants are for the most part well lighted and ventilated, and many of them are air-conditioned.

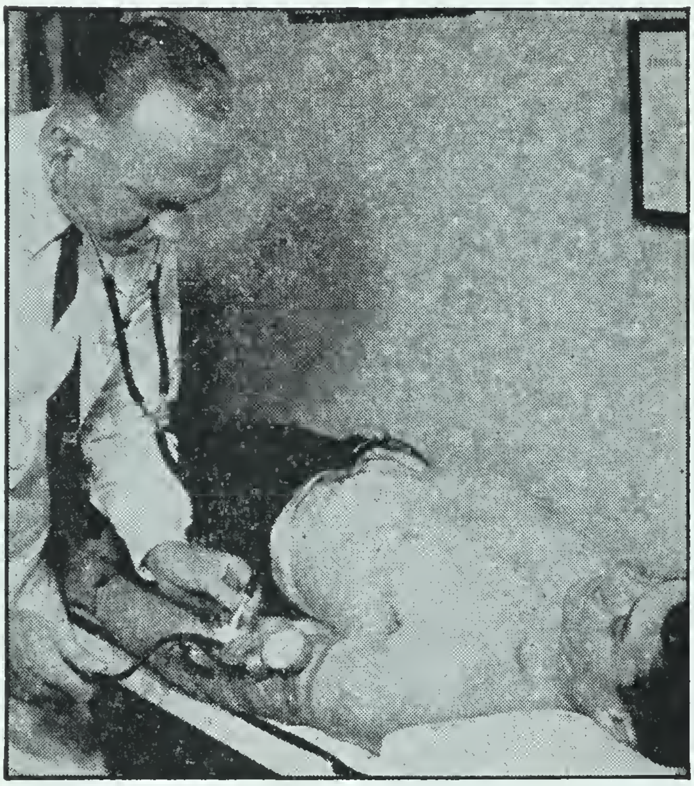


Courtesy Douglas Aircraft

Fig. 351. Health hazards are minimized in modern, well-lighted, air-conditioned plants equipped with machines which have the best safety devices. This photo shows the interior of a plant during a blackout.

Another safety factor is that all divisions of work require very high standards of mental and physical fitness. Good health and proper physical condition eliminate many industrial accidents. The regular physical examinations—often given at the expense of the company—are of great personal value as they may reveal some trouble which, because of its early recognition, is easily remedied.

The hazards of flying itself, which originally were a factor in the high salaries of pilots, have been very largely eliminated. The chances for advancement in aviation depend much upon the training and work experience which will make promotion to the desired position possible. Personnel men who do the hiring are themselves frequently chosen from among superintendents and foremen who have first-hand information of the qualities and abilities needed in each job. In some lines, promotion comes more easily than it does in others, and as in other types of work some jobs are "dead-end" ones. They do not lead directly to any others. But there are often ways to get out of these if one is ambitious. Some companies give to new employees a statement of qualifications for other jobs in the department, together with suggestions as to how one may fit himself for promotion. For the person who is willing to put forth extra effort and study, aviation offers more opportunities for advancement than do most industries.

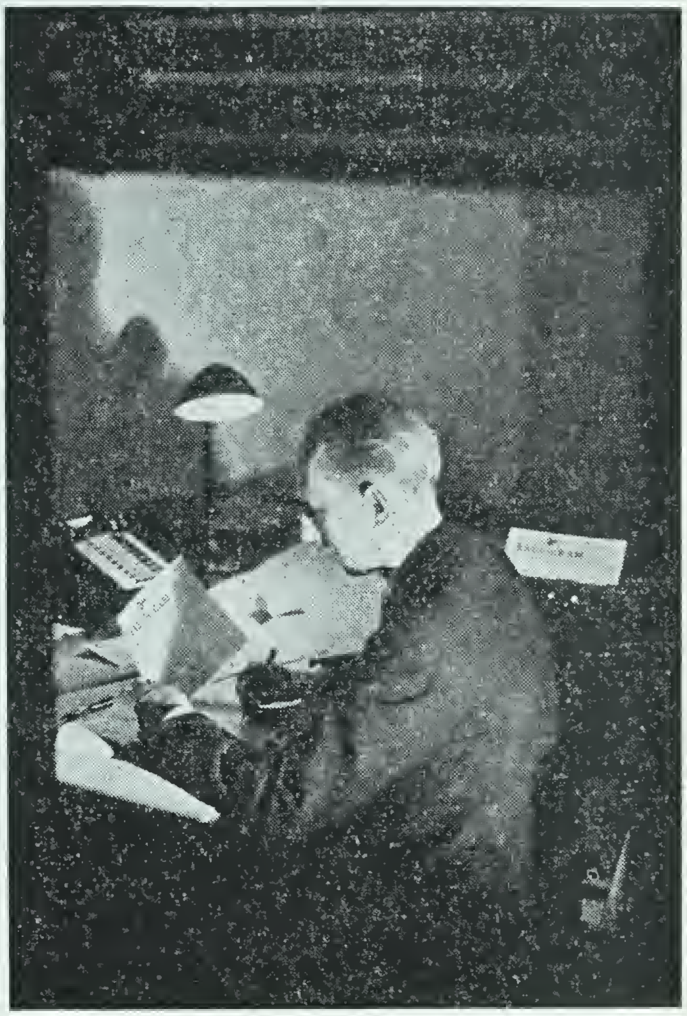


Courtesy American Airlines

Fig. 352. Doctor taking a reclining blood-pressure test. Periodic health examinations must be passed by many aeronautics workers. Conditions of ill health are often prevented, because these checks locate weaknesses early.

Many of the manufacturing companies, as well as the airlines, operate their plants throughout the twenty-four-hour period. Under this plan, shifts are necessary. Common hours for shifts are from the hours eight to four; four to twelve; and twelve to eight. Employees may be moved regularly for a time from one shift to another, or they may have to stay on a shift for a long period of time. Sometimes jobs require that work be done at specially designated hours which are scattered throughout the twenty-four-hour period. Persons who fly will have their working hours in terms of flying schedules. This may make it necessary to be absent from home certain days and nights each week. When irregular periods of work on a job are recognized and planned for previously to obtaining the job, they are less likely to prove irritating or disappointing.

The foregoing discussion is given to help in an intelligent consideration of some things to be examined in selecting a vocation. Again remember that no job is perfect. Although the other fellow's job may appear ideal, closer scrutiny and investigation will show that it has its disadvantages too. The industry is new, and there is always a special satisfaction in being part of a great new development; especially is this so when as in the case of aviation one can see its influence in the whole political, social, and economic life of the world. In addition to the normal advantages of aviation, one of the immediate values is that right now the country needs fliers. At present, there is a clear, patriotic duty to learn something of the industry, and, if one is qualified, to learn to fly. That patriotic duty is also involved in the future in the keeping of the peace. There is little question but that the nation that has a reserve of trained pilots and of flying personnel upon which to draw in time of need will have safety in that reserve. Probably the field of aviation, on the whole, has fewer disadvantages and more advantages than do most of the great industries.



Courtesy Pan American Airways

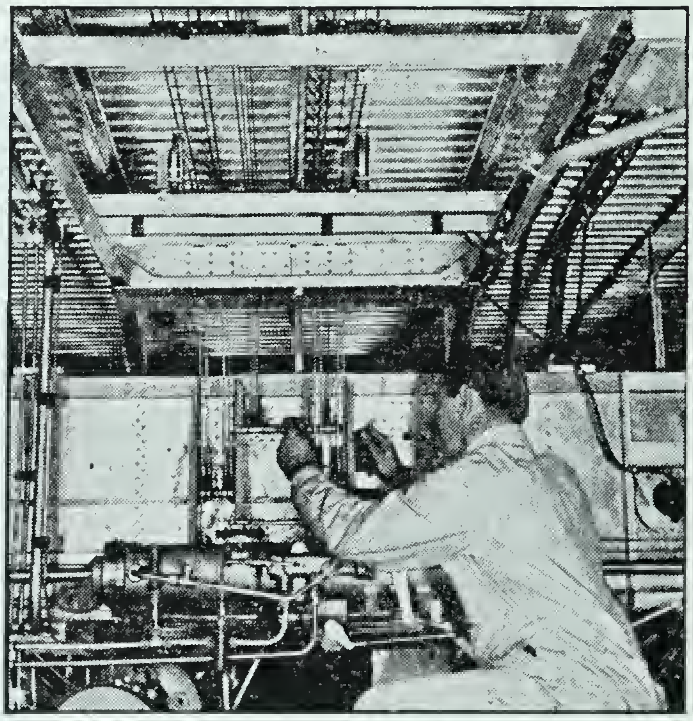
Fig. 353. Some jobs require night work. This flight watch is on the night shift

Exercise 5. Arrange for individual members of the class to talk to workers in different types of aeronautical or related jobs about the advantages and disadvantages of their jobs. Ask specifically about the things mentioned in this problem. Report findings to the class.

Exercise 6. Obtain from a local insurance agent the workmen's compensation ratings for employees in aeronautical jobs as compared with other jobs of similar nature. Explain to the class the significance of the different ratings.

Problem 3. How much general and specialized training is characteristic of the various kinds of jobs in aeronautics?

Free public schools make it easy for the great majority of people of America today to complete a high school education. Consequently, in many fields of activity high school graduation marks the lower limit of training for eligibility for work. In many fields of work additional training in school or college, or special experience, or both are necessary before one can secure permanent or well-paying positions. As soon as one is fairly sure of what he wishes to prepare for and of his ability to do it, he should begin to outline the necessary course of training. If education is wisely planned, it will help towards more than one possible kind of work and will guarantee greater satisfaction in any kind of employment. Sound training in the use of English is important for everybody. Neither will anyone go amiss through the study of science and mathematics. For those interested in the mechanical or technical aspects of aviation science and mathematics are especially important.

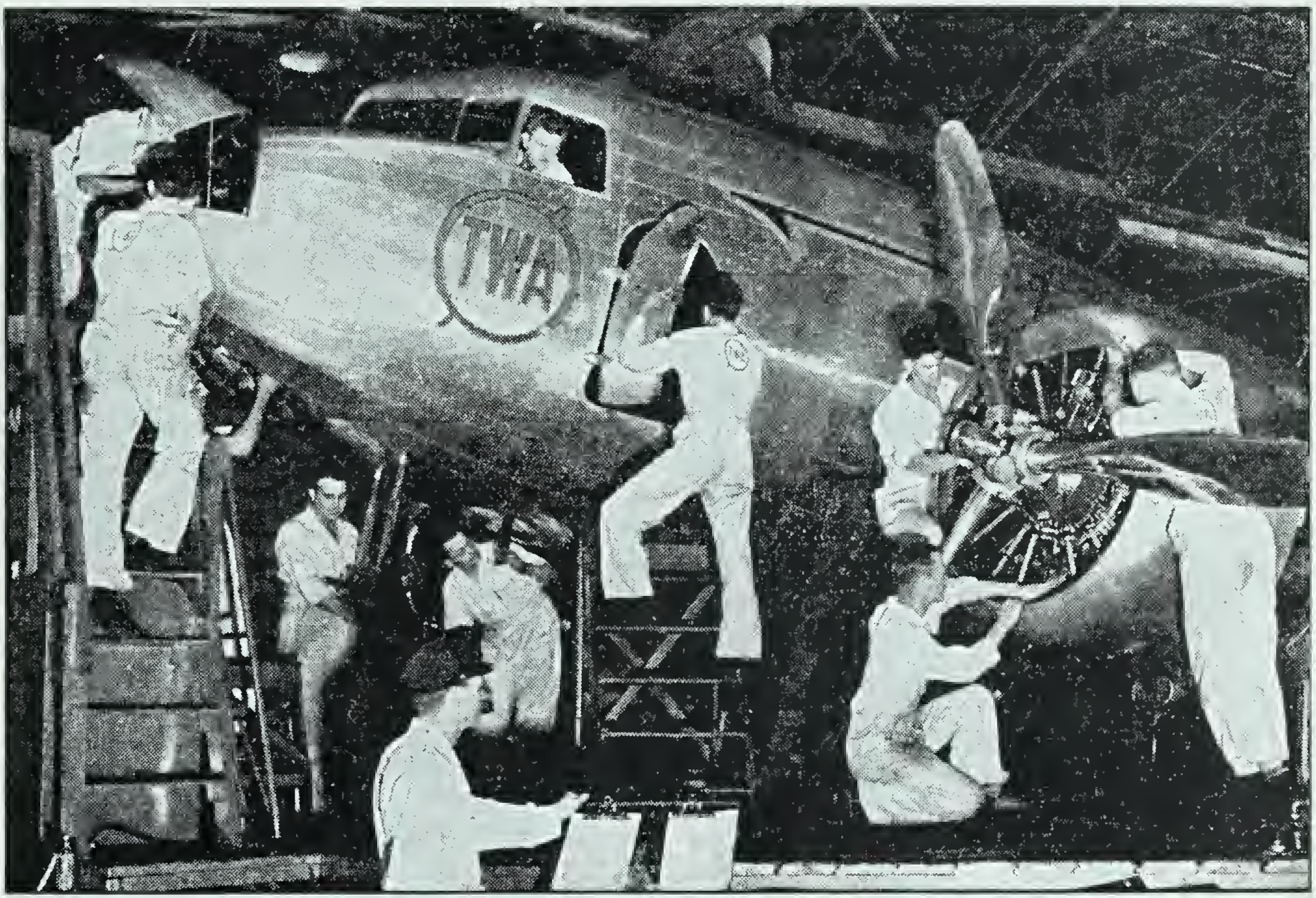


Courtesy American Steel and Wire Company

Fig. 354. A vital inspection job. One error here is too many. This man makes the final adjustments and inspection on control cables inside a large plane. Check and double check is the watchword in plane manufacture.

Many jobs in both the large and the small manufacturing plants do not require much, if any, specialized training. Others require terms of varying length of specific training in a certain trade. The one thing which they all do demand is accuracy. The airplane is one of the most carefully built machines which can be found. Every part is made with a high degree of exactness and tested for minute flaws. Again the operation of the plane and all air traffic are carried on under the most rigid and precise inspection. The slightest adjustment or alteration on even a private plane must be inspected by a licensed mechanic. It follows that any educational program leading to a place in any phase of the industry must be one which prepares a person to work with the utmost care and exactness, to be absolutely honest in admitting any accident or error, and to be willing to submit to systematic and severe criticism.

It is impossible in a chapter of this length to describe in detail the training required for each position in such a diversified field as aviation. Statements will be made concerning certain general groups of jobs recognizing that each particular job may have some special requirement and that the requirements vary somewhat with the supply of labor and with the company. Some of the companies publish material stating the qualifications necessary for work in their various departments.

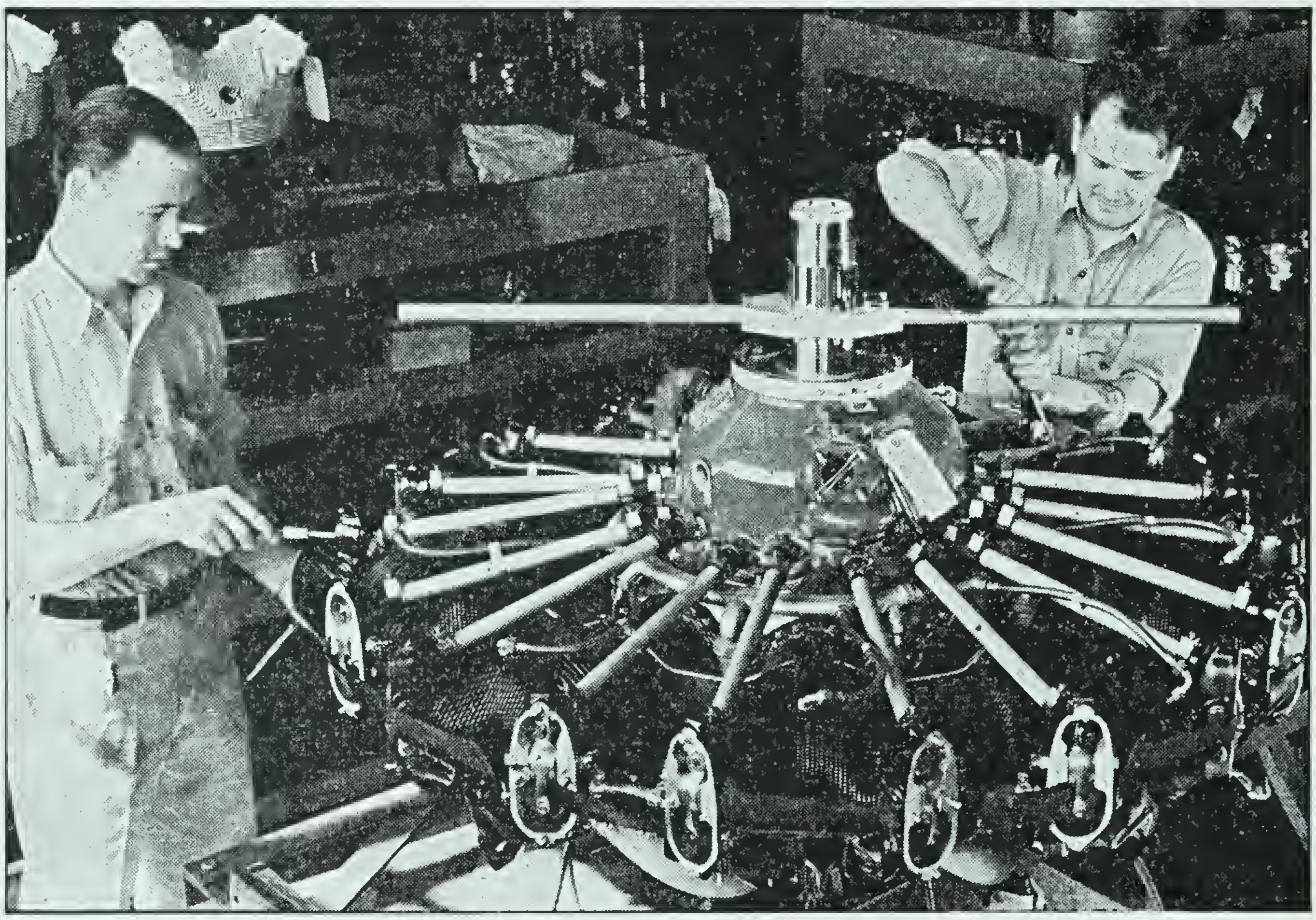


Courtesy Transcontinental and Western Air, Inc.

Fig. 355. Maintenance overhaul. Master and apprentice mechanics swarm over a transport at a maintenance base. Careful check is made on all vital parts. Certificated master mechanics must actually do, or personally supervise, all work.

As has been said, there are very few jobs which will lead to advancement for those with less than a high school education. This is as far as most of those have gone who work as mechanics, on assembly lines, in stockrooms, as operators of simple machines, and in like capacities. There is some evidence that many college graduates are not happy in jobs such as these and do not do very well in them.

High school pupils who plan to take up mechanical work will do well if they take courses in mathematics, science, shop work, auto mechanics, and drafting. Either on-the-job or special training in such things as blueprinting, welding, and machine operating will become necessary before one is promoted. Courses in those operations are now offered in many public high schools and trade schools and by many schools run commercially. Some state and governmental agencies give the special training necessary for many types of work. Courses in mechanical drawing, drafting, and many other subjects are sold by correspondence schools. Many of the private enterprises giving such training are educationally sound and financially honest. Unfortunately, this is not true of all of them. One should exercise a good deal of care, therefore, before enrolling in such a school. In many branches of the armed forces training is given to enlisted men which will fit them for good positions in the aviation industry while they are in the service and after their discharge. The training secured in



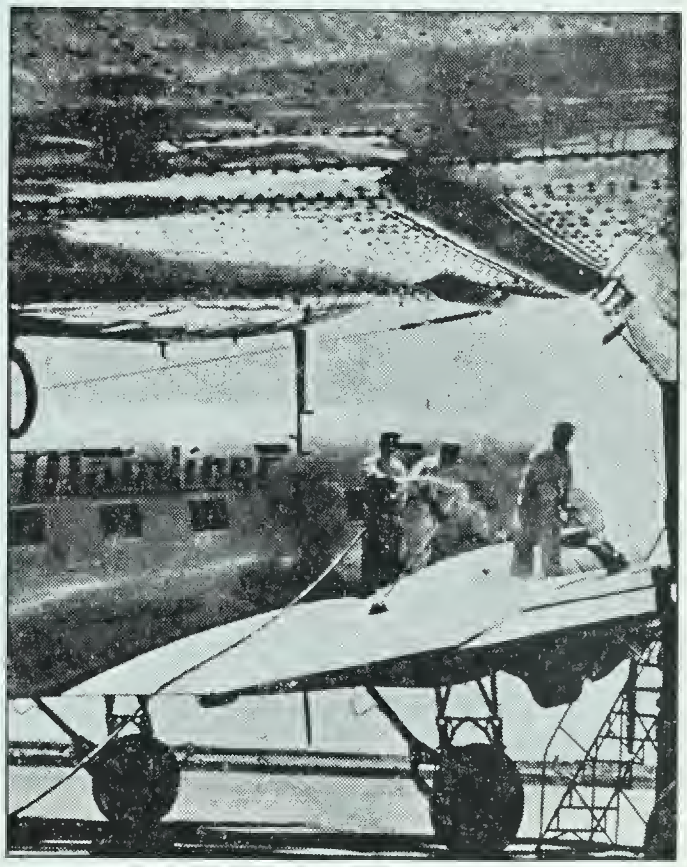
Courtesy American Airlines

Fig. 356. Master mechanics holding certificates issued by the Civil Aeronautics Administration work on all engines. Apprentices may help them. Here the engines are taken off the plane and completely disassembled, cleaned, checked, reassembled, and thoroughly tested.

these schools is of the very finest and is, of course, at the expense of the Government. Some of the aircraft companies themselves provide the means for giving their employees the special training needed for advancement in the industry.

Aircraft and engine mechanics are very important persons in the aeronautics industry. There are several classifications of mechanics, all of whom are licensed by the Civil Aeronautics Administration in the same way as are pilots. Mechanics must complete a specified amount of training in a recognized school and have actual experience under the supervision of well-trained master mechanics before they attain the rating themselves. As a rule this training requires at least two years of time at a cost of $500 or more.

Although an aviation mechanic above the apprentice grade must have a Civil Aeronautics Administration certificate as an aircraft mechanic, or an engine mechanic, or an aircraft and engine mechanic, there are, of course, many jobs in airplane shops, both in airline and in private and municipal shops, as well as in engine factories, which do not require a Government license. The men who are responsible for the mechanical work on aircraft or their engines must be licensed, whether they work at private or municipal fields or with the airlines. Anyone holding a job not requiring the license works under a licensed mechanic.



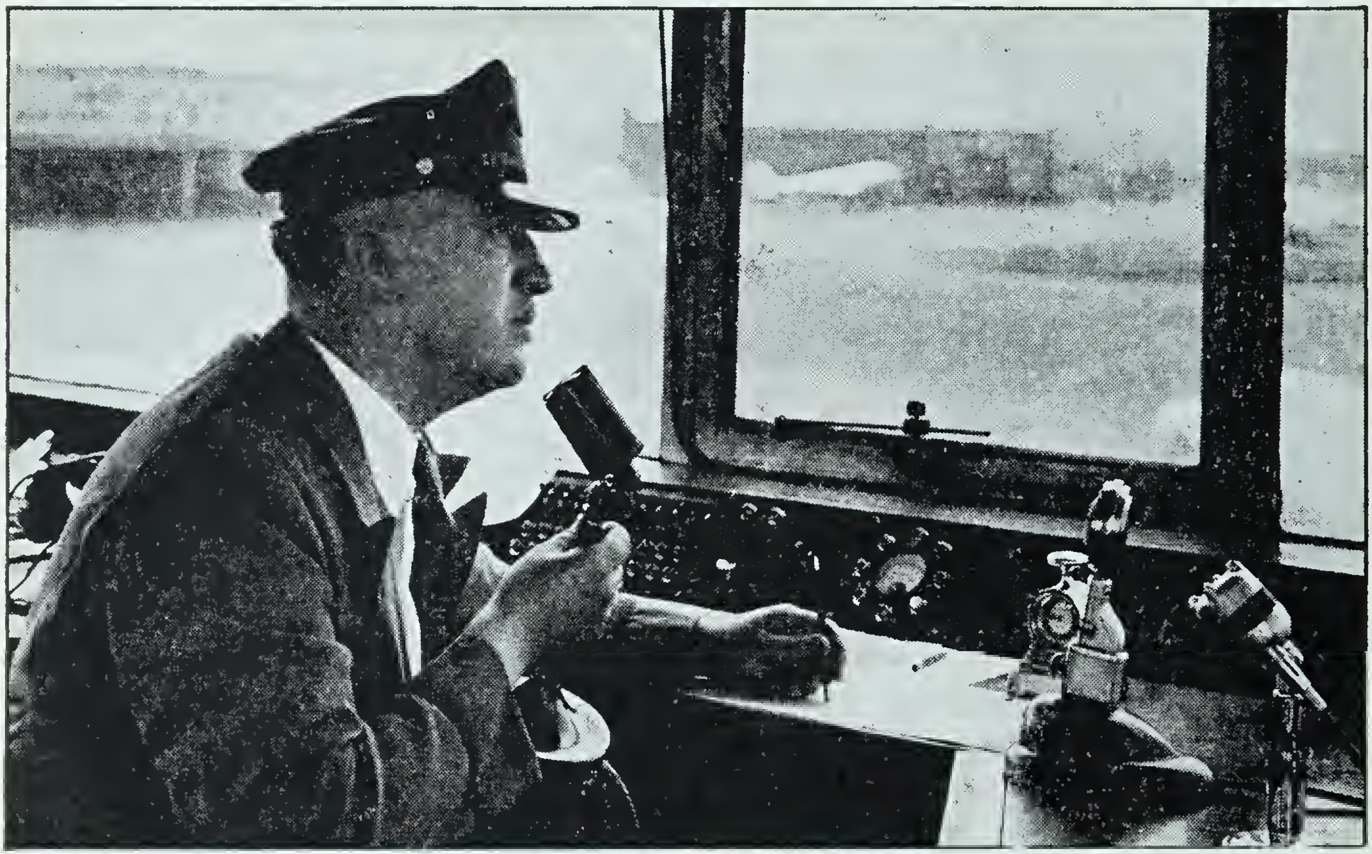
Courtesy United Air Lines

Fig. 357. Service crew at work. Among other things, the mechanics' helpers and apprentices scrub and shine the planes. Even this job requires training and the careful following of instructions.

There are varieties of the better technical or engineering positions for which a college or university education, with special training along the particular lines chosen, is necessary or at least highly desirable. Meteorology, for example, is a highly specialized field and one for which college preparation is undoubtedly the best. Not only are the technical courses pertaining to the subject necessary, but an ability to type at least forty words a minute and some knowledge of geography are being required.

An airline dispatcher is, in many instances, a retired pilot or a person who started as a meteorologist. In all cases he is a man of extensive training, and in all cases a certain amount of actual airline experience is required.

An aeronautical engineer probably will be a graduate of an engineering school, as will a radio engineer or operator. A few aviation schools are equipped to give this training.

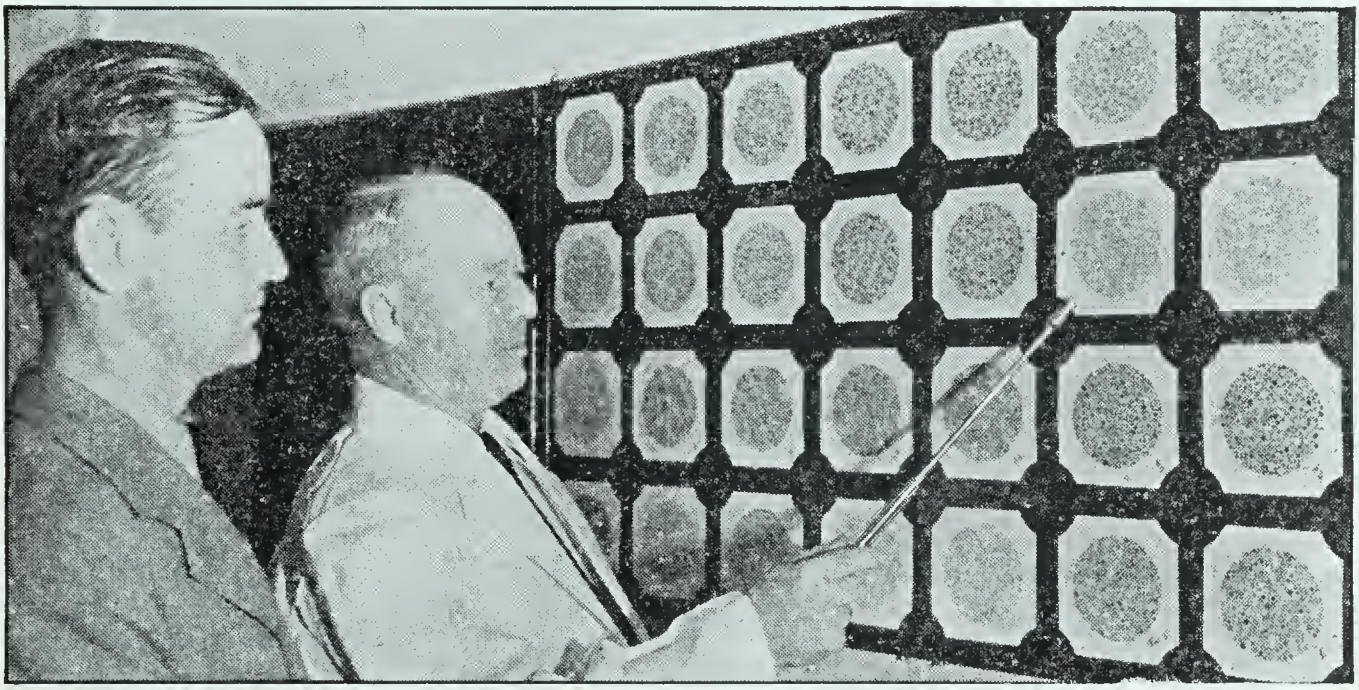


Courtesy United Air Lines

Fig. 358. Airway control officers regulate airline traffic at busy airports. When within the immediate areas of large airports, pilots keep in almost continuous radio contact with the tower operators who advise them of air traffic in the vicinity and the ground weather conditions. No plane takes off without approval from the officer.

In general it may be said that a college or university education, including perferably both general and technical courses, is to be chosen, if possible, by those in any of the specialized fields of aviation. This does not imply the impossibility of success for the non-college person, but the one who has gone to college *and profited from it* will have an important advantage over his non-college competitor.

As has been mentioned, the airline pilot is one of the most highly selected men in aviation. In addition to especially rigid physical requirements, he must have extensive educational and practical experience. Many pilots have been college men. It is possible to secure the necessary training without going to college, but at least two years in a college of engineering are desirable. In any event one must study mathematics, physics, engines, meteorology, and similar subjects. There are, of course, many hours of flight training. In some of the best aviation schools the training for airline piloting and engineering can be accomplished in about two years at a cost of from $4000 to $5000. A person who cannot afford this sum may enlist in the air force of the Army or Navy but will be required to serve in the military forces for a certain time (about four years) after completion of training.



Courtesy United Air Lines

Fig. 359. Pilots and certain other employees must pass color-blindness tests. These charts consist of variously colored spots. Those with normal vision see a certain well-defined figure, while color-blind persons see a different figure.

While one may obtain a pilot's license entitling him to fly his own plane or to fly for commercial—not passenger—purposes without meeting the standards of an airline pilot, even he must pass the rigid examinations in Civil Air Regulations (C. A. R.), meteorology, navigation, and plane maintenance; also he must pass a rigid test-flight examination. The training as a private pilot usually costs about $375. Any of this work which one did not take in college he will take in a special school. The Civilian Pilot Training Program courses (C. P. T. P.) administered by the Federal Government (C. A. A.) provide pilot training for thousands of young people. During the war this program is training men from 18 to 37 for Army duty in the transport service, cargo and mail service, tow-target pilots, instructors, glider pilots, liaison pilots. Pilots for the Navy are also trained by C. A. A. There are also many private schools for training aviators as well as for aviation mechanics. The Civil Aeronautics Administration issues a list of the private schools which are approved for such training. Great care should be taken in choosing, even from among approved schools, the one in which a person may be most likely to get the best work.

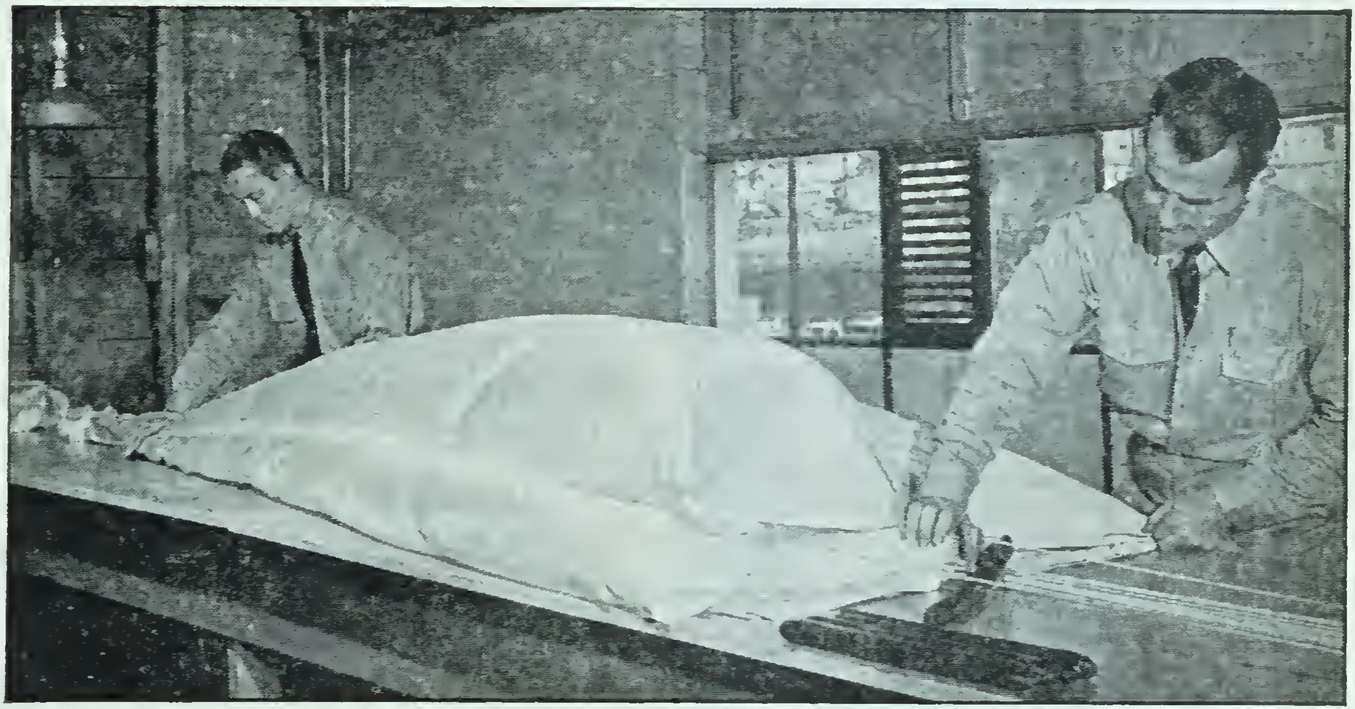
The preparation of a stewardess is primarily that of a nurse's training. This involves at least high school graduation, and then a nurse's course of three years. This course includes work in such subjects as anatomy, chemistry, physiology, bacteriology, psychology, as well as hospital training which is in itself arduous and not always pleasant. Those persons who are employed as stewardesses are given a short course of special training by the companies which employ them. A searching physical examination is required of each with frequent rechecks.

Those who are to participate in the business side of the industry will, of course, take the special training suitable to the department involved. To a larger and larger extent stenographers, secretaries, accountants, traffic clerks, to say nothing of the managers, purchasing agents, and others of the office personnel are college graduates whose major courses have been in commercial work, economics, or business administration. As is true in many other jobs, there are many persons who have and others who will secure excellent positions without additional schooling beyond high school. One should not be discouraged if it is not possible to go to college. On the other hand, if it is possible to go, one should seize the opportunity.

Exercise 7. Refer to the classified lists of jobs prepared for Exercise 1 or Exercise 2 in Problem 1, and reclassify these jobs according to the kind and amount of training needed. In so far as possible, arrange the various jobs according to such groups as *(a)* no special training beyond high school necessary, *(b)* special high-school courses necessary, *(c)* technological or trade training necessary, *(d)* college training necessary, *(e)* special experience and training necessary. Make up additional classifications for jobs that do not fit these suggestions. Probably there will be jobs that no member of the class can classify. If you are interested in one or more of these, write to employers of workers of this type to determine necessary educational and experience qualifications. Report your findings to other members of the class who may be interested.

Problem 4. How does high school experience relate to employment in aeronautics?

As has already been learned, the aeronautics industry at one place or another employs persons with about any kind of training imaginable. There is something to do for those of any interest. But here as elsewhere the person whose education really helps him is the one who watches all the time to see *how* it can help him—how what he learns in a course, or what he sees when he goes on a trip, or what he does when he works around the house can be useful to him in something he is going to do. It is surprising in how many ways any of our courses or any of our other experiences can be of aid to us *if we will only look for those ways.* So if one is interested in any phase of aeronautics, it is a good thing for him to think how the other things he is doing will aid him in that field. He will find, of course, that some of his present activities are more closely related to aeronautics than are some others, but there will be few experiences which are not of some value. It does not necessarily mean that a person should be urged to take a particular subject, or engage in a particular experience in order to get these values. Rather it means



Courtesy Ryan Aeronautical Company

Fig. 360. Are you clever at folding linens and making beds? Can you follow precise directions? While this picture shows men folding a parachute, many women are employed in this work. A mistake in this job is not an error; it is murder.

that he should look for the values in what he is doing. Later he may choose to do certain things because of the special help he will receive from them.

Modern languages have never been as useful as they will be in the near future. As air travel gives us such command over space that we can travel almost around the world as fast as we now cross this country by automobile, we shall have more and more occasion to use the language of other peoples. The person who knows some German, or French, or Spanish, or Portuguese will have favored opportunities in either the technical or the commercial side of the aviation industry. And do not forget Chinese, Russian, and other tongues.

The application to aviation of any work which one does in his courses in mathematics or in natural science is easily seen. Algebra is often used in the making of flight calculations. Geometry is employed in designing and navigation; physics and mathematics are employed in airplane designing, instrument construction and calibration, stress analysis, airway lighting, lubrication research, and the like; and not only mathematics but some knowledge of meteorology and astronomy are employed in actual flying. One of the great opportunities is in the field of chemistry, where plastic materials, new types of lights, tough metals, new fuels, and the like are being developed. In every phase of engineering, physics and mathematics, of course, are basic. Also one can apply the biological sciences. Altitude flying raises questions of physiology. If a person is interested in botany or zoölogy, he may apply this interest too. The problem of the transportation of insect pests and plant diseases by airplane is a matter of immense significance.

Similarly, if one is handy at repairing an automobile, if he can repair the electrical contrivances about the house, if he has a camera and processes his own films, the skill so fostered may be of real service to him. Every kind of mechanical aptitude is used in aviation.

Some individuals have opportunities to travel during holidays, and some have opportunities to visit airfields and take trips by air. Some have visited airplane factories, or ticket offices, or radio broadcasting stations. Some are able to secure vacation employment or out-of-school jobs. Some have made gliders or model airplanes; some have read magazines or books devoted to airplanes and air transportation; some have relatives or friends who already are employed in some branch of air service. If each will keep his eyes open, he will be amazed at the number of ways he can secure information and skill which will not only make him better able to understand the place of aircraft in our society, but also may help fit him for some job in the field of aviation.

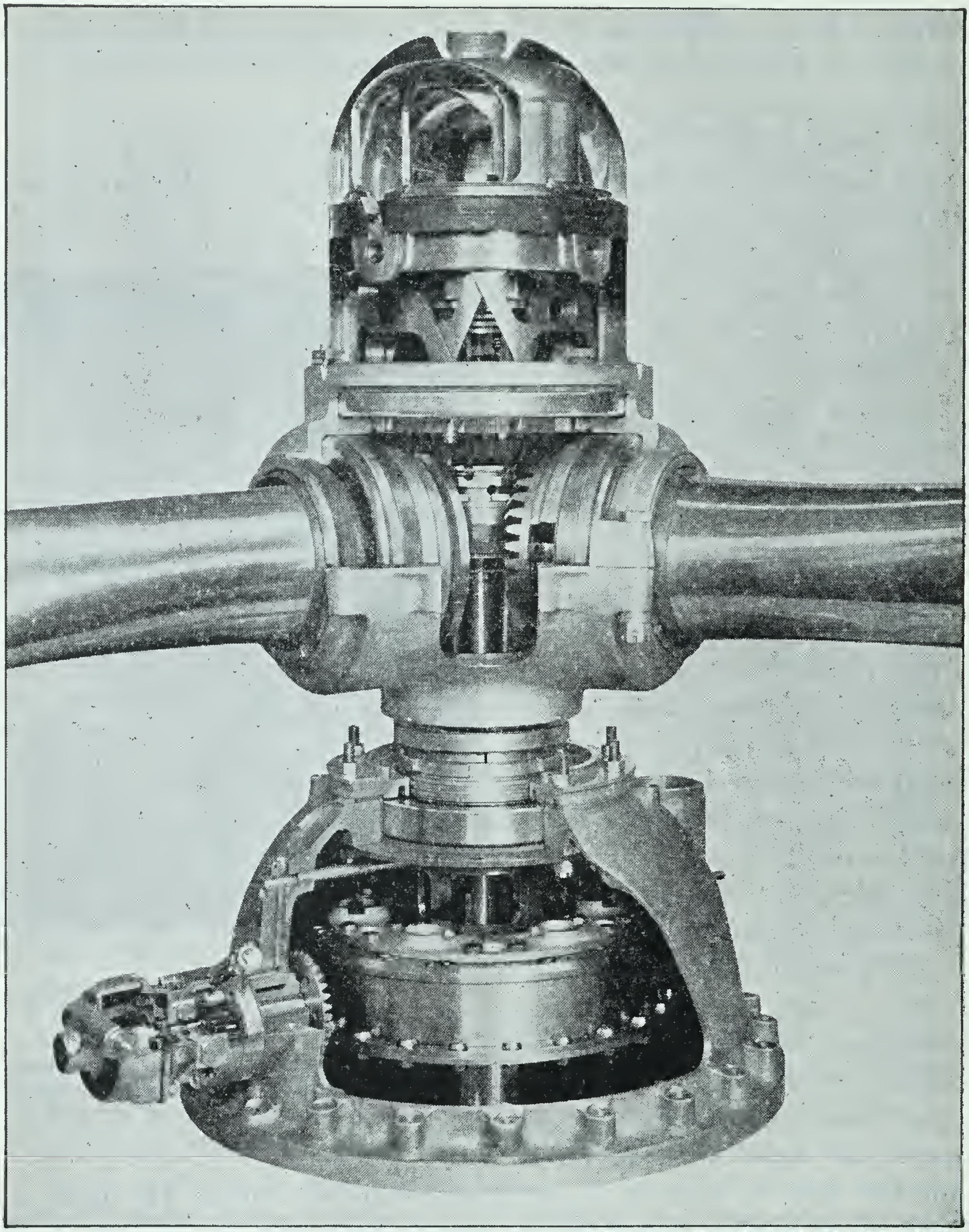
Would it not be worth while to go over each course in school, each of the activities of the school, each job and other out-of-school experience which any of the class has had, to see what each contributes in the way of information or skill which may be needed in the choosing and the securing of a job?

It is quite possible that someone will say, "Oh, yes, all the subjects I study and almost everything else I do may help somewhat in fitting me for a job in aviation, but certainly some things don't help very much. Why should I spend so much time and effort on studies which at most will not do me much good and which I may not use at all? Why not spend all of my time on the things I am sure will directly contribute to the job I want to do?"

These are the various answers to these questions. In the first place, no one should go to school merely to get ready for a job. More important than the particular work he is to do is the fact that he is to be an informed, cultured citizen. He needs to understand and to appreciate the world about him. To be sure, if he is interested in aviation, he should try to see in all his studies their application to aeronautics, but at the same time he should try to see their application to the other activities of a generally useful citizen. In the second place, no person wishes deliberately to limit his advancement, and almost without exception those persons who rise to high positions know more than just how to do their jobs. They are widely educated in general. The more a person knows about a

Courtesy Douglas Aircraft

Fig. 361. This boy is operating a machine used to produce blueprints. This job like many others can lead to advancement in various departments for the wide awake chap who takes advantage of the opportunity to study the things he handles on the job.



Courtesy Hamilton Standard Propeller

Fig. 362. Hydromatic propeller mechanism. This moderately complex machine is representative of the type of device many aircraft workers have to understand. Notice the mechanical perfection of the fitted parts. Precision and accuracy are of paramount importance in all aircraft manufacture.

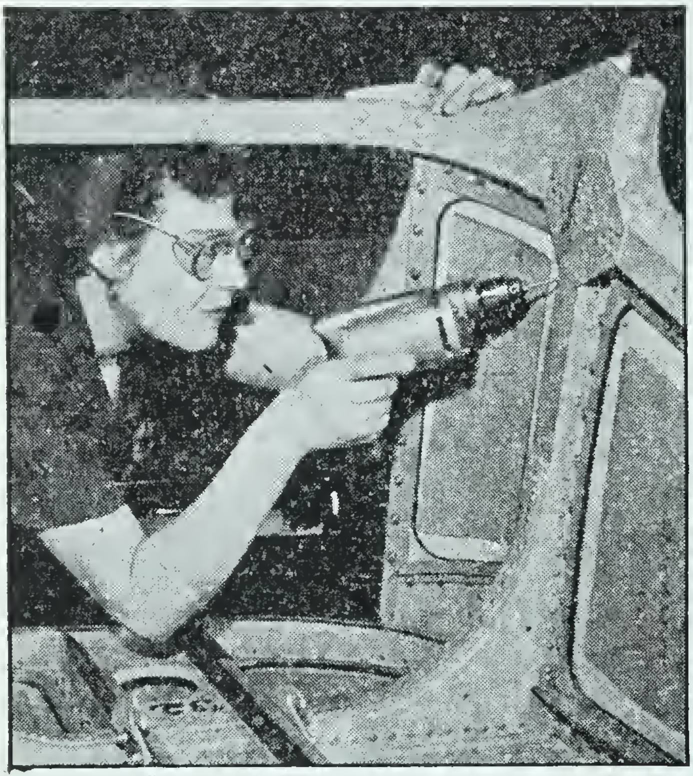
great number of things, the more things he can do, the more likely he will be to adjust to changes in his work and, therefore, the more likely he will be to secure advancement in position.

A high school is not intended merely to prepare persons for particular jobs; it gives them certain understandings and helps them to develop certain skills and attitudes which they will want to have whatever they do, just as this course is intended to aid in the understanding of many things about the aeronautics industry, not merely or even primarily to give all the preparation needed for any particular kind of work. In the course of his high school work, it is hoped that each person will discover the work in which he will be able to succeed. It is especially important to remember that *how well* one does a certain piece of work is one of the best indications there is of how well he will do other work of a like kind. It is a great mistake to think that one can "play along," doing sloppy work in his language and his mathematics in high school because there is plenty of time to settle down to business when he gets on a job or goes on to college. While this may turn out to be true in very rare instances, it does not usually work out that way.

Courtesy United Air Lines

Fig. 363. It is necessary for this clerk to know the parts he must handle; consequently this job requires some training and experience. Beginners in this department must keep the stocks clean and in order. This job can lead to advancement for the worker who is alert to learn.

There have been many studies which have shown that the best way to foretell how a person will stand in his college work is to know what his grades were in high school. If a person likes algebra and geometry and does well in them in high school, there is a good chance that he can take up successfully in college the courses which deal with the mathematical aspects of aeronautics. If he likes drawing and is precise and accurate in his work in high school, it is likely that he will succeed if he wishes in drafting. If he enjoys writing and his composition is good, the chances are that he can learn fairly easily to qualify for journalistic, or advertising, or other writing aspects of aviation. If he is a good mixer and likes to be with people, he will probably continue to develop this ability along several lines. If a girl likes to cook and make people comfortable, it may be that she may go on to develop the qualifications of a stewardess. But almost never does one who is low in any of these respects in his high school experience do *very* well in them in college. Exceptions do occur sometimes, of course, when a person with poor achievement but good ability gets fired with great ambition.



Courtesy Lockheed Aircraft Corporation

Fig. 364. This job is on an assembly line. It requires comparatively little specialized training but must be very accurately done. Have you used this type of machine in the school shop?

In every job in the aviation industry, the standards are high. Even in work which requires little skill, the job must be done right. No shiftless work is tolerated. Whether it be sweeping the floor of the waiting room, washing the plane, mapping an air route, serving a meal to a passenger, or tooling a precision instrument, one must do his work well to get and to hold his job. To secure advancement, his performance must be approaching perfection. So the earlier one begins to do his very best, especially along the lines in which he thinks he wants to work permanently, the quicker he will be able to learn about how far he can hope to go.

This does not imply that a person has to have high ability in order to get along well in any aviation job. As has been pointed out, there are many places in the industry for all kinds of people. Some jobs require more speed, or a higher degree of exactness, or a greater emotional control than do others. There are positions which do not require a knowledge of algebra, or the ability to use a foreign language, or even much facility in the use of English. There are thousands of jobs in airplane factories which demand only that a person patiently and regularly perform a single operation all day long, day after day, without getting restless, without feeling monotony. Some who find school work difficult will do very well indeed in these kinds of work. Some persons will advance more rapidly than do others. But in these types of work as in the more technical ones, whatever is done must be done well.

Exercise 8. Have each member of the class select one high school subject he has had and outline briefly to the remainder of the class certain specific things he learned that would be helpful in a certain aeronautical job. As this is being done, some member of the class should serve as blackboard secretary to keep a record of the contributions from each of the high school subjects to aeronautical work. The class may wish to prepare a summary of this list to post on the school bulletin board for the benefit of all pupils in the school.

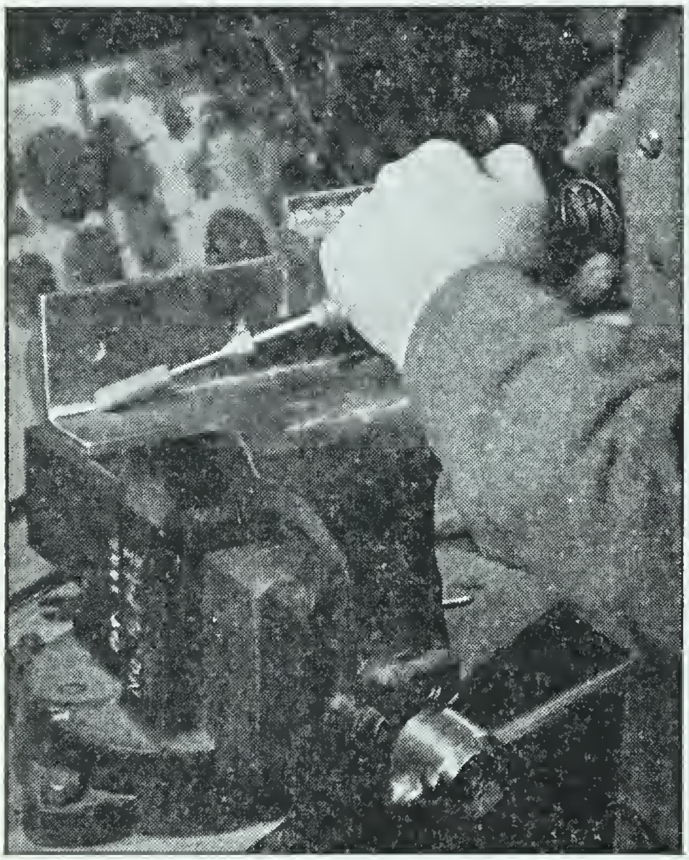
Exercise 9. Follow the same procedure as in Exercise 8 for extra-curricular activities or clubs, work experiences, recreation, travel, and other out-of-school experiences.

Problem 5. What personal characteristics are necessary for jobs in aviation?

Every person wants to qualify himself for the very best job he is capable of holding. Of course, not all can do each particular thing equally well. Some people seem to acquire "just naturally" the abilities which make them good stenographers, good engineers, good mechanics, good executives, good electricians, and so on; and others reach a stage of high efficiency only after long, hard work. How does a person go about it to find out what he can do best? Is there any satisfactory way except just to get a job at something and try it out? It is to be hoped that there is a better plan than this, for certainly it is a very wasteful method. A person would have to work for several weeks or months before it would become clear whether or not he was succeeding, and it would take a lifetime perhaps to find the one job he could do best. On the other hand, when he found a job at which he could succeed he might stay at it, though as a matter of fact he could have done a much more important task at a higher rate of pay had he just known he was able to do it.

This last condition, even though a man earns a living, is unfortunate for him and the industry, for it is as important to have the best men in positions utilizing all of their ability as it is to keep persons from jobs for which they are not suited.

It seems easy at first to find out how well a person can do a particular thing. If he can run faster than anyone else in his community, if he sells more insurance than anyone else in town, if he stands at the top of his class in geometry or at the top in the average of all school subjects, if he is on the winning debating team, we think he is surely one of high talent. But just how strong is he? A boy may win the 100-yard dash in his local school but not "place" in a district—to say nothing of a state—meet. He may lead his class in geometry but still be much less capable than a person in another school who in that school was given a lower mark. He may sell a great deal of insurance in his home town but completely lack success in a large city. To get any accurate estimate of a person's abilities, he must be compared with those of a large number of other persons, not only persons of the home town but others in other towns. Sometimes an exact measure can be secured—the number of seconds in which the 100-yard dash can be run—but still a person doesn't know how good he is until he knows in how many seconds most people can run it, and also what the record time is. So it is not enough to know that a person stands at the head of his class in history or typing. The question is, does he understand history as well as or better than most who have studied it as much as he has? How many words per minute without error can he do on a typewriter? Not only should one find out just how rapidly and accurately he can perform certain mechanical operations, but it should be asked if he is interested in mechanical things, and an



Courtesy Behr-Manning

Fig. 365. The manufacturers of abrasives find numerous applications for their products in the aeronautics industry. This type of work can be learned in the school shop. Manual dexterity is of great value in such jobs.

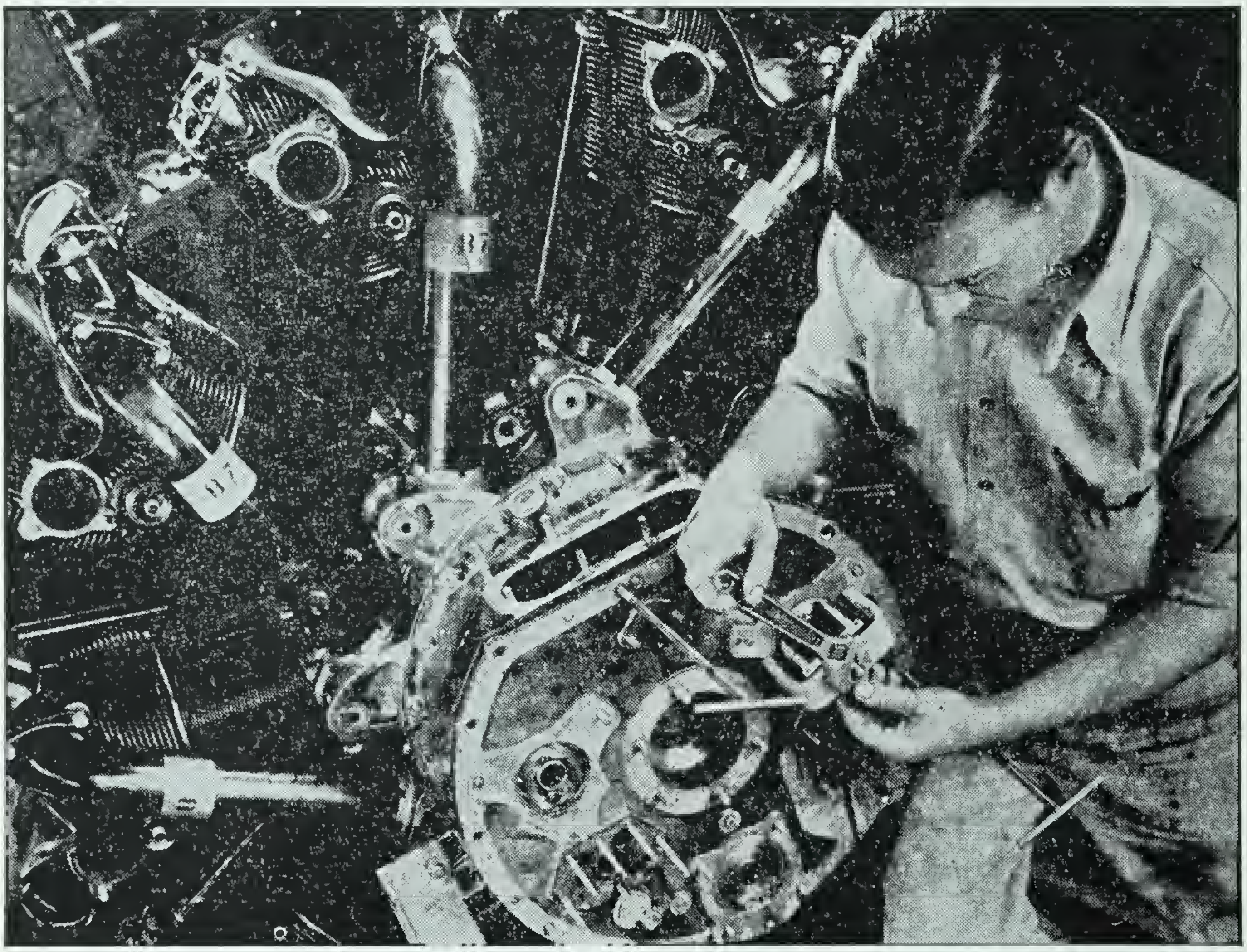
attempt should be made to see to what degree his interests make it likely that he will succeed in mechanical work. There are means by which these things can be estimated with a fair degree of accuracy.

One's interest in or his aversion to a given kind of work is an immensely important factor in his success to it. Some persons just don't like to fuss around machines. Even though such persons might be able to learn about mechanical appliances and even though they had good motor coördination and were highly accurate, it might not be wise for them to try to become mechanics. They would be unlikely to be happy in their work and they would be likely to make mistakes and to incur injuries. It has been stated that many women are being employed in various mechanical jobs in aircraft manufacture. A woman may have the physical skill and the patience to hold a job on an assembly line. But she must not be unwilling to get her hands and clothes greasy and to wear her hair under a cap. A person who would rather be alone than with people will probably not do his best work in a crowded office. One who heartily dislikes mathematics —even though he is good at it—will probably be unwise to choose aeronautical engineering as a career.

Not infrequently a person learns about *one phase* of an occupation and becomes interested in that phase. He thinks, then, he would like to get ready for that occupation, when as a matter of fact there are other parts of the work which he doesn't like at all. A girl likes to prepare and serve meals, is successful at putting people at ease at parties and so is sure she wants to be a stewardess. But if she dislikes to handle crying babies and can't stand to be near an air-sick passenger, she will do well to consider something else. A boy thinks it would be very satisfying to sell tickets and to help plan air trips, but he must also be willing without losing his own temper to listen to complaints of passengers who could not secure the desired accommodations or whose
parties, and so is sure she wants to be a stewardess. But if she dislikes

Not only an individual's interests but his aptitudes should be considered. By an *aptitude* is meant a person's prospective ability—the likelihood that he will be able to acquire rapidly skill or understanding along a particular line. To have an aptitude for designing does not imply that a person is now expert in making designs. It means that with the proper training and information he *may become* expert. Aptitudes are estimated by observing what a person has already done in terms of his opportunities. There are many different aptitudes and combinations of aptitudes which are essential for success in various branches of aeronautics. Some of the more important ones will be mentioned here.

There is, for example, the linguistic aptitude—the ability to acquire easily the knowledge of and the accurate use of language, either one's own tongue or a foreign one. A carpenter does not need to use a very large number of words, but an executive must have a wide command of language. He must be able to talk intelligently not only with those from all of the departments of his own occupation but also with those from other occupations and industries more or less related to his. Some very extensive studies have shown that even the size of the vocabulary, the number of words to which the exact meaning can be given, increases regularly with the position in industry from laborer, through foreman, head of department, and so on to the highest executive. Persons in secretarial or personnel work also have need of language aptitude.

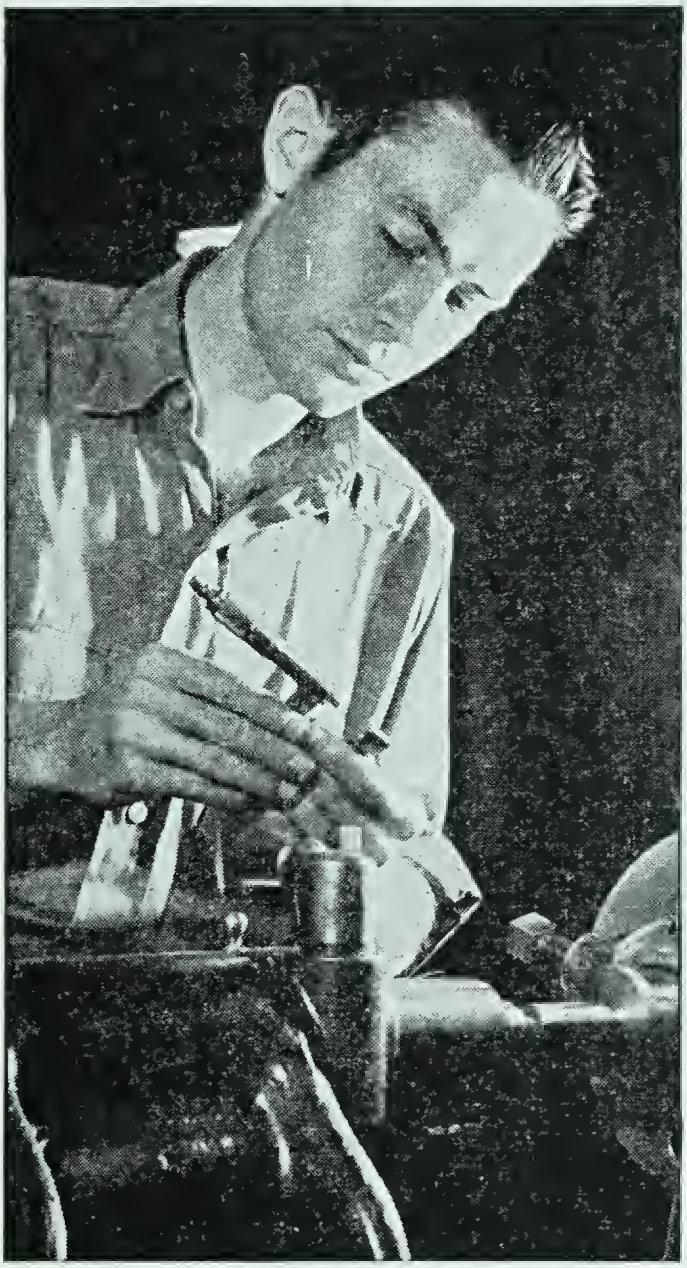


Courtesy Eastern Air Lines

Fig. 366. Mechanics must know how intricate mechanisms work.

An aptitude for numerical, or quantitative, thinking is required in a large number of aeronautical activities. This ability to deal with numbers and number relationships is used in many different ways and in different degrees in various departments. In some instances about all that is needed is to count accurately. In most engineering work a relatively large amount of mathematics is necessary—the amount increasing with the better and more technical positions; in tool production, shop mathematics is essential; in financial departments one must be able to prepare payrolls, tax returns, insurance and other statistical reports. There is much work to be done in aviation which does not need the exercise of much quantitative thinking, but, generally speaking, the possession of this aptitude will be of distinct advantage in almost any department except those involving just routine processes, like assembly lines.

In drafting one must be able to see how a structure will appear from any position. Any mechanic above the rank of helper must be able to read blueprints. A large portion of mechanical ability is the recognition of the relationship among parts of a machine. The navigator and the pilot must be able to read maps and to identify formations seen from all angles. These things imply an aptitude for accurate apprehension of spatial relations which is also needed for success in all phases of engineering and designing.



Courtesy Lockheed Aircraft Corporation

Fig. 367. A young machinist checking measurement of a steel shank in a lathe. He uses a micrometer. Micrometer reading may be learned in the school shop or physics laboratory. What may happen if the worker makes an error?

Closely related to the ability to deal with spatial relationship is the aptitude for manual dexterity which is inherent in such things as the ability to draw, to adjust delicate machines, to do two or three operations at once, to put together the parts of a contrivance, or to operate business machines. There are ever so many other operations which require highly exact performance. Some of the processes in aircraft manufacture are done with the very highest degrees of accuracy. Measurements are made and parts constructed to $\frac{1}{10{,}000}$ of an inch. Even large pieces like engine blocks must be handled with exceptional care.

It is also exceedingly valuable to one wishing to engage in aviation employment to be able to execute operations with speed and precision. In most cases speed is not as important as accuracy (on the assembly line speed is mostly standardized), but the one who can be both rapid and exact has a great advantage over the slower person in typewriting or in running a calculating machine, in the independent assembly of parts, in the adjustment to emergency situations in flying. Speed, when coupled with precision, is all-important.

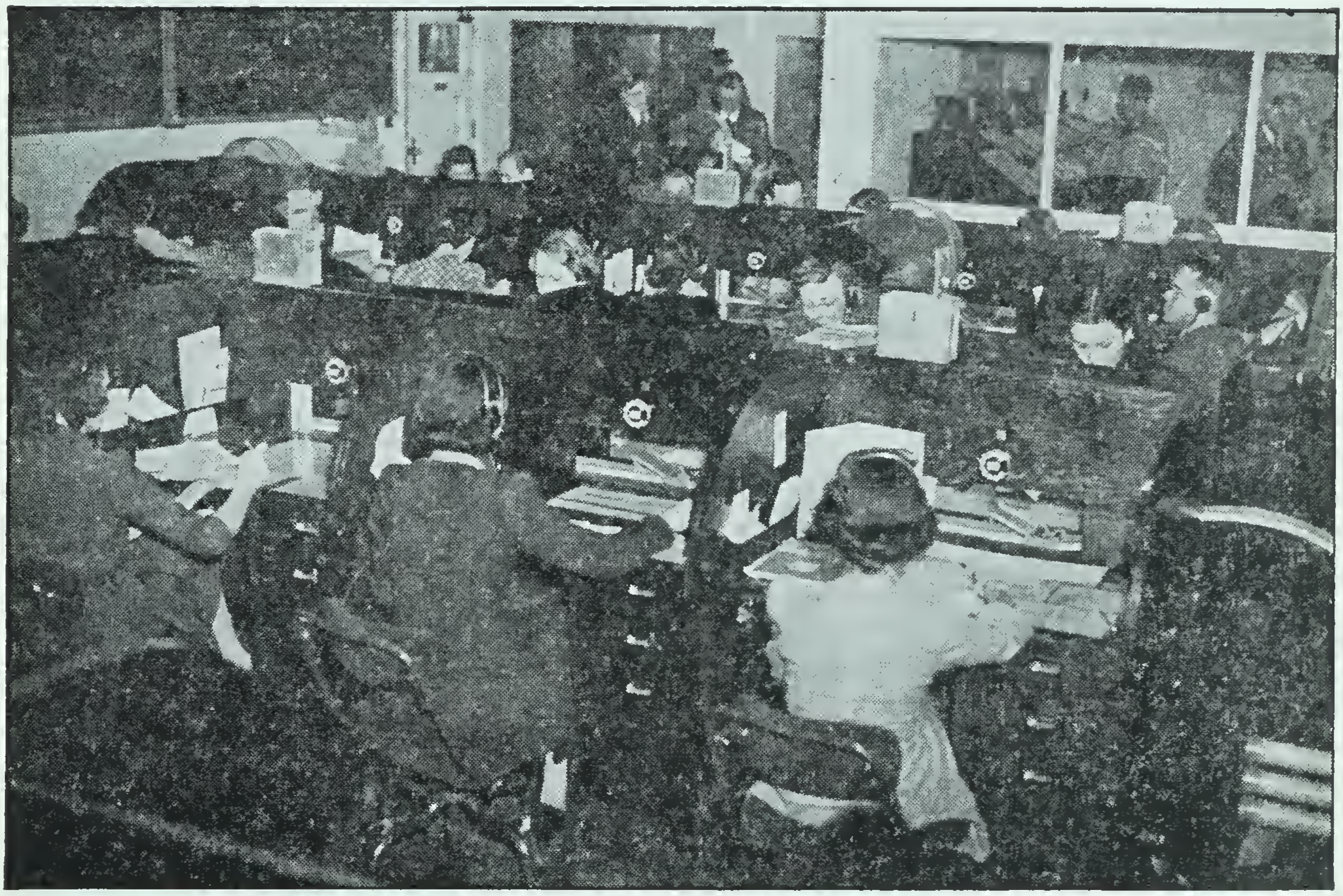
Courtesy Transcontinental and Air, Inc.

Fig. 368. The airline hostess. Serving meals, caring for children, helping passengers and performing a multitude of similar jobs makes the life of a hostess interesting but strenuous.

The artistically inclined person has many opportunities to develop his talent. The designing of planes is done primarily with respect to utility and to principles of aeronautical engineering. But good design is almost always artistic, and there are many problems arising concerning matters of decoration. Airports must be landscaped, waiting rooms decorated, printed matter emblazoned. Wherever the public is touched by the industry there is an opportunity for real artistic talent to be utilized. As long as the airplane is still thought of as something new, it will continue to be true that all connected with it are bound to be public-relations persons. The ability to dress and appear appropriately and in good taste will always work to an individual's advantage.

So, too, and partly for the same reason will sociability be an asset. In certain positions which require intimate contact with people, sociability is necessary in high degree, for example, in the positions of executives, advertising managers, stewardesses, persons in employment and other personnel offices. It goes without saying, too, that the one who has a "way with people" is the one most likely to secure advancement.

Still another aptitude which should be cultivated by all who possess it is the development of emotional control and the ability to keep cool in emergencies. Some seem always to do the right thing in times of crisis. They keep cool, do not forget instructions; they take charge of the situation and direct others. Persons vary immensely in this respect. As emergencies may arise anywhere, this self-control is desirable in anybody, but, obviously, such a quality is valued most where crises are most likely to occur. It is essential in any work connected with actual flying. The stewardess must be able not only to keep calm herself but to inspire calmness in others. The pilot must think quickly and confidently if an engine fails or he

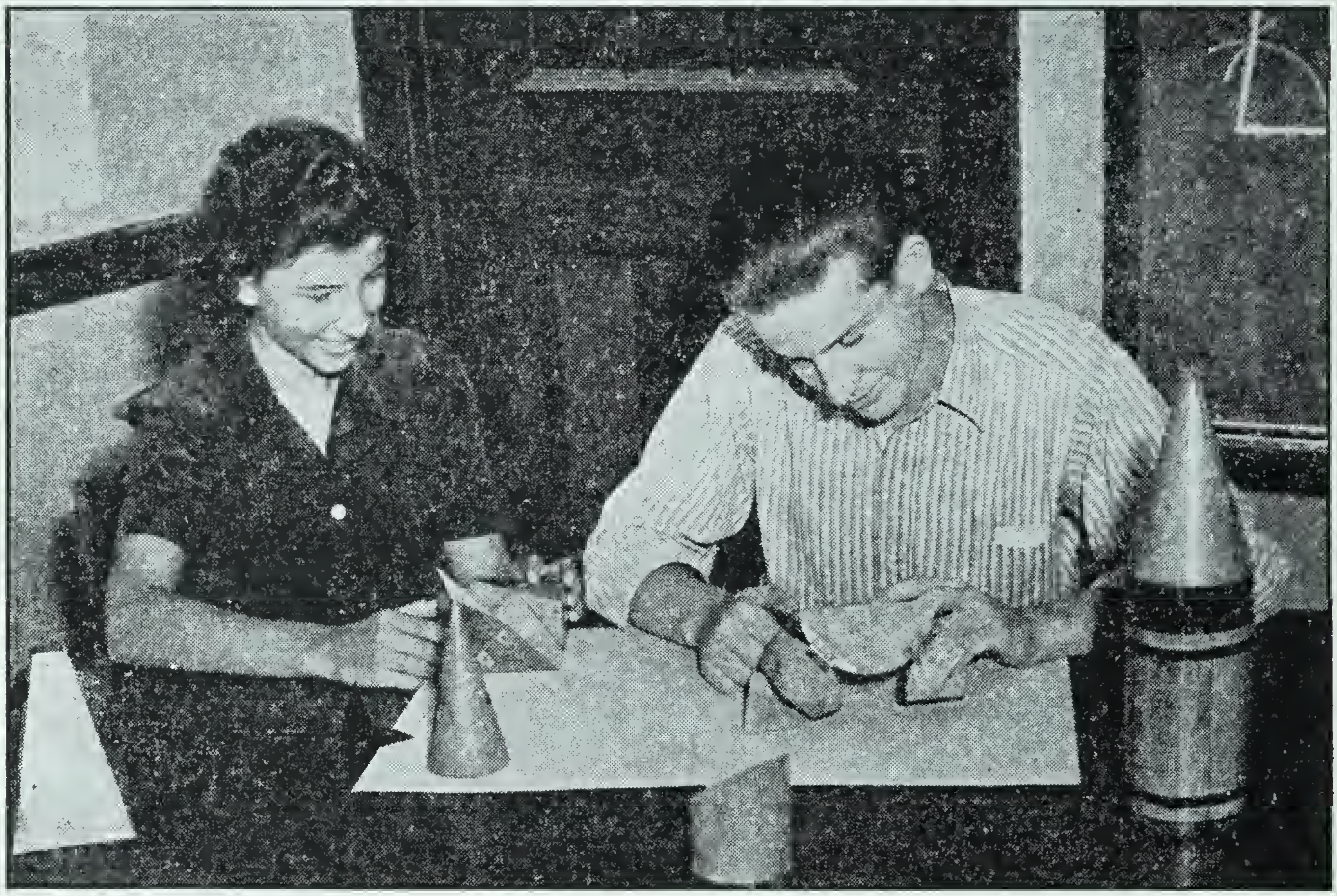


Courtesy Eastern Air Lines

Fig. 369. Unfailing courtesy must be given to every telephone call in this reservations department. These workers handle a total of more than 2000 calls daily giving each caller prompt attention to his needs.

encounters an unexpected storm. Sometimes a passenger who cannot secure the reservation he wants, or whose plane has been grounded by bad weather becomes irate and unreasonable. The ticket agent or traffic manager must keep his own temper and calm down his customer. Emotional self-control is a prime characteristic of a good executive.

There is another very important personality characteristic of which no mention has yet been made. This is the ability to accept criticism graciously. Everyone wants to do his best, and criticisms and suggestions given to workers are intended to help them do their best and should be accepted in that spirit. The person who sulks or shows resentment because his errors are pointed out, who tries to defend his work rather than to correct it, like the chronic "griper," will soon be searching for other employment.

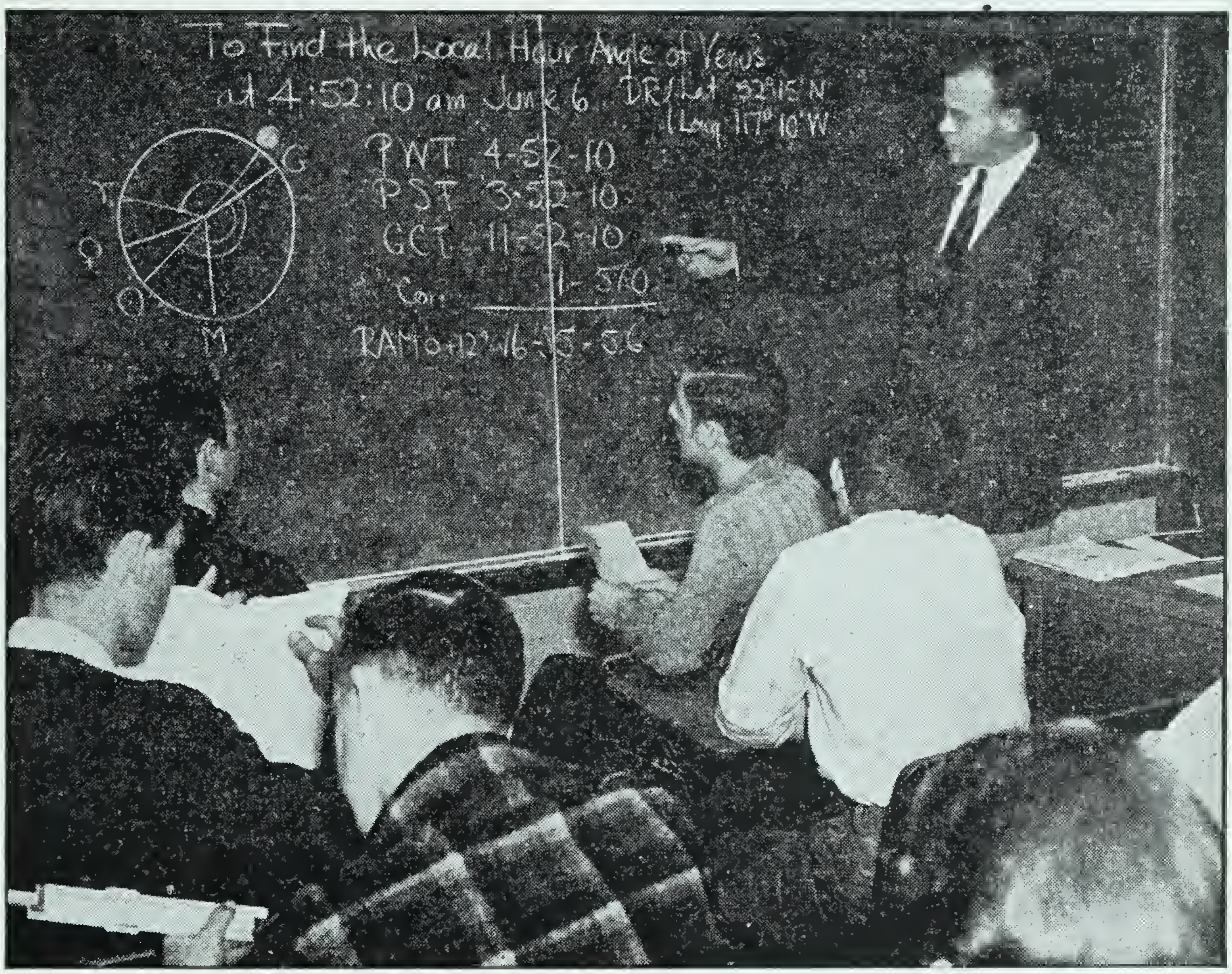


Courtesy Visual Instruction Center, San Diego Public Schools

Fig. 370. High school students will find many applications of geometry in aeronautics.

Up to this point abilities related to success in different types of jobs have been discussed individually. Of course in most occupations one finds combinations of abilities. An engineer, for example, must not only possess an ability in mathematics, but also he must have developed an aptitude for spatial relations. If he is to advance to an executive position, he will find it essential, too, to have good ability in language and in emotional self-control and sociability. Indeed by the time one becomes an executive in an engineering department, he will have probably displayed about all of the aptitudes which have been described.

To become a radio operator one needs a numerical aptitude, a fair amount of a linguistic aptitude, manual dexterity, and speed. A mechanic should have an aptitude for spatial relations, manual dexterity, and precision. If he is to advance there must be also a numerical aptitude, and, to a fair extent, a linguistic one.

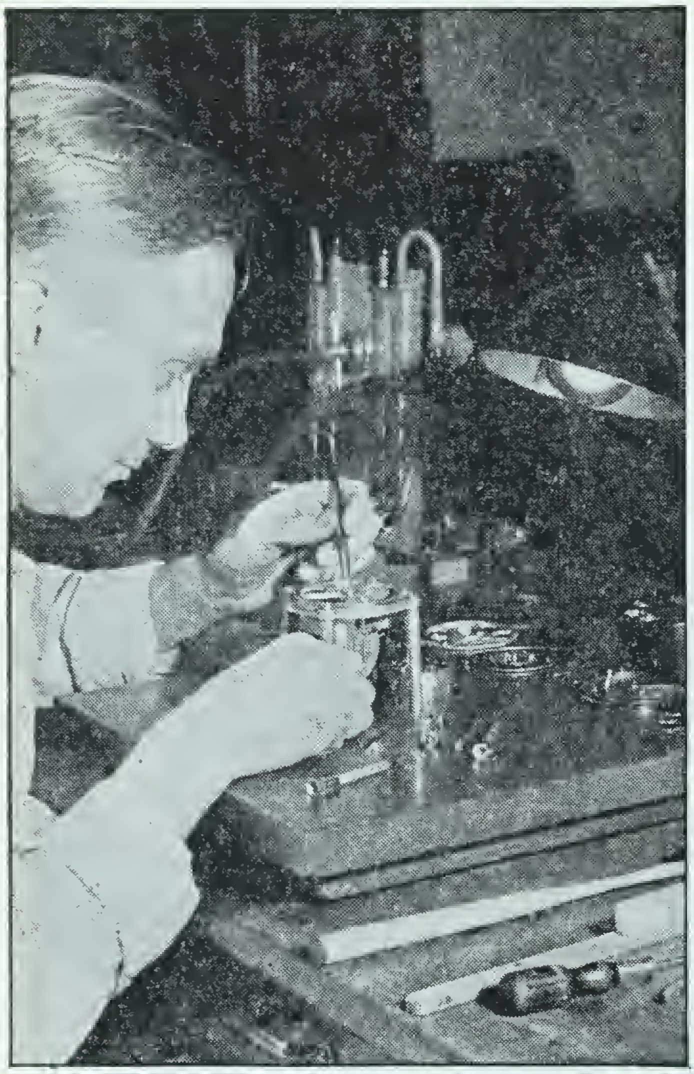


Courtesy Visual Instruction Center, San Diego Public Schools

Fig. 371. These high school students are applying mathematics and science to a problem in navigation.

A stenographer must have linguistic ability, manual dexterity, speed, and precision. If she is to become a secretary, there must also be sociability and emotional control. Sociability and emotional control are assets anywhere.

No one can tell the exact amounts or combinations of abilities needed for particular jobs and positions, nor, indeed, are there any very exact measures of them. It is quite true, too, that sometimes individuals who do not exhibit the aptitudes described do succeed because of some especially developed abilities or because of some particular circumstance.



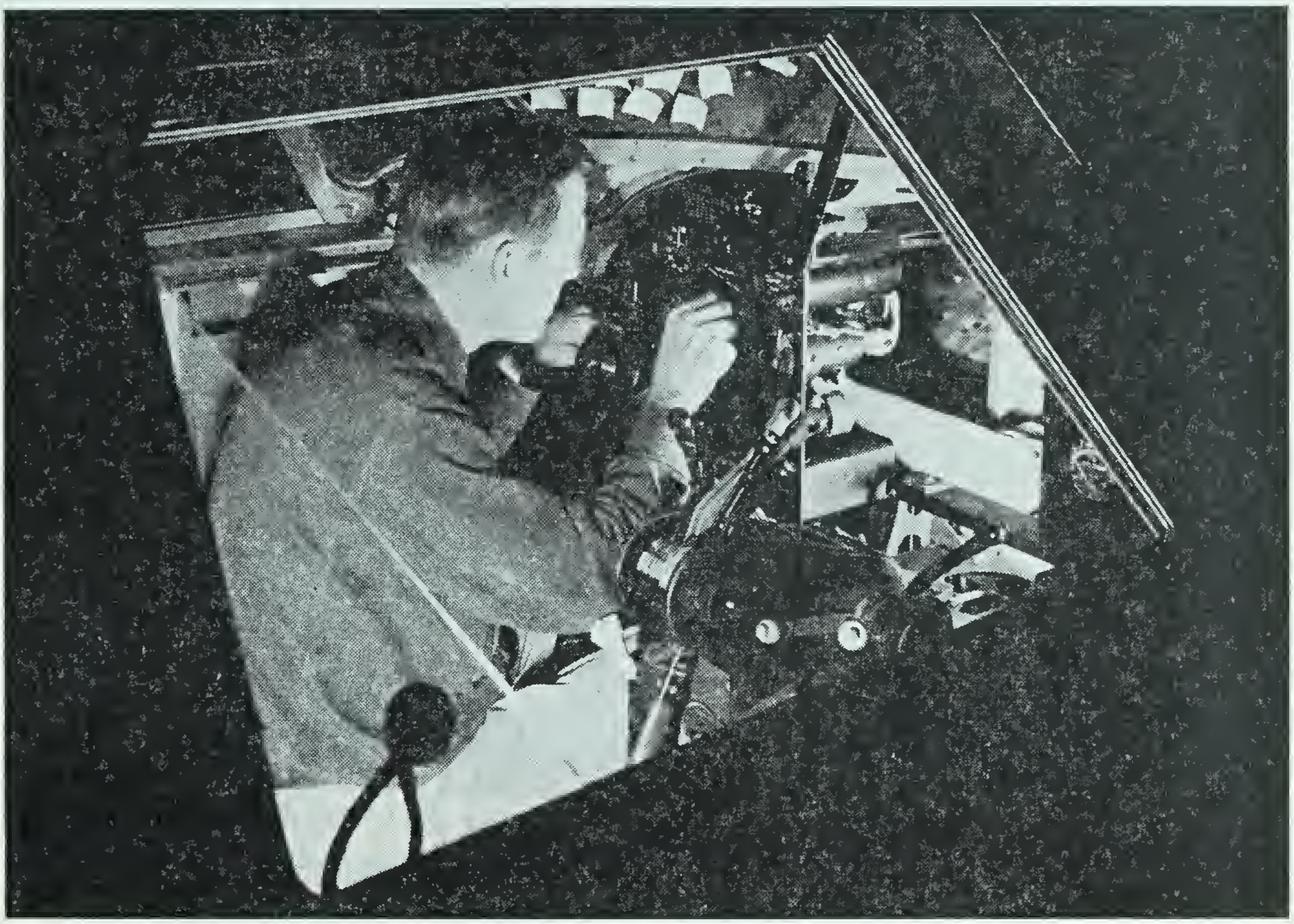
Courtesy Transcontinental and Western Air, Inc.

Fig. 372. This job requires a high degree of manual dexterity. Precision, speed, and a knowledge of the fundamental principles upon which the instruments operate are essential. No errors are permissible. This worker is reassembling an altimeter after cleaning and checking.

It is obviously not particularly valuable for a high school student to know what abilities are required for success in a job unless he has some way of telling whether or not he has these abilities or the aptitudes for them. How can he find out? There are three ways in which one can get some idea as to his aptitudes: (1) by an examination of the things he is now doing, (2) by devising some simple tests for himself, and (3) by getting some qualified person to administer to him some of the carefully standardized tests which have been developed for these purposes.

1. A person who has taken these subjects knows whether he likes or dislikes algebra and geometry, and whether or not he has really found it easy to understand them. He knows whether he has been interested in how machines are put together; whether he knows how to find out what is the matter with the car; whether he is fairly skillful in repairing things like an electric fixture; or in building model airplanes; or, on the other hand, whether his "fingers are all thumbs" when it comes to handling small objects or several objects at once. Most persons can find out fairly easily whether they read as rapidly and as well as others in their classes, whether they know the meanings of the words they encounter in

their general reading. They know whether they enjoy using a dictionary, writing letters, and saying things in new ways. Again, most individuals do not need to be told whether or not they meet strangers easily, whether they take the lead in organizing the activities at social gatherings, and the like. Similarly almost everyone has been present at certain kinds of emergencies and can think back to see whether in such situations he was quick to see what could and ought to be done and was able to do it, whether he was one of those who became excited or "petrified" while someone else took charge of the situation. In the presence of an accident, did he aid in the care of those injured or did he shrink from such a task? In such ways as these a person can get some idea of his present abilities and by comparing what he now does with what others of his age and experience do, he can estimate roughly—but only roughly—what the probabilities are of developing these aptitudes so as to be qualified for particular jobs.



Courtesy Lockheed Aircraft Corporation

Fig. 373. This man is inspecting the instrument panel in a large plane. What high school experiences would be helpful in learning this job?

2. It might be well for a person to try himself out at various tasks

involving some of the abilities which have been discussed. He might see whether he can put together a Yale lock, or read a blueprint, or make a model airplane to scale, or alphabetize a large number of names cut at random from a phone book. If he can persuade some others to do these same things and find how rapidly and accurately he does them as compared with others, so much the better. However, one should not be discouraged if he does not do things new to him as rapidly as some others do them. The important point is, can he easily see what is to be done and then learn to do it effectively?

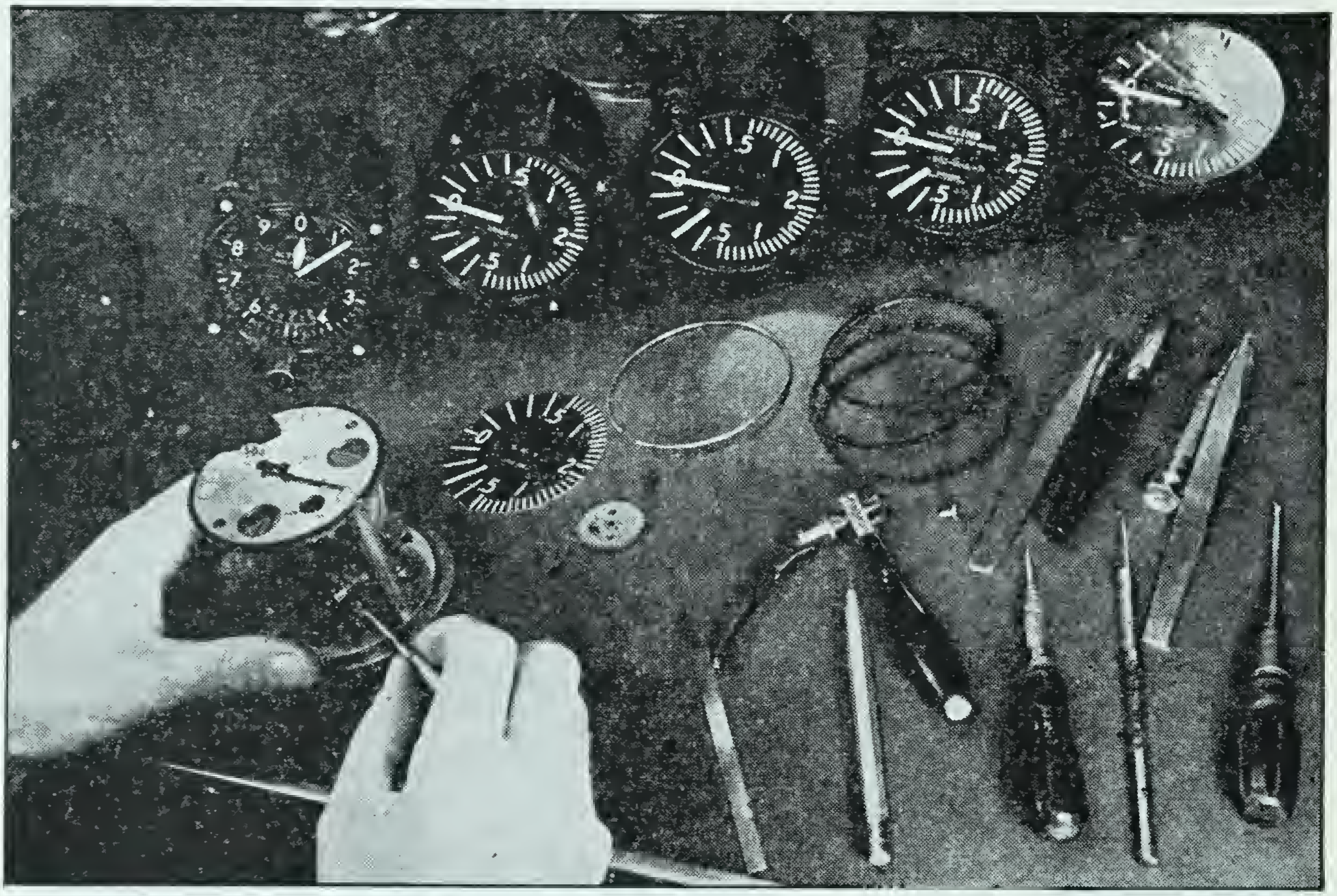

Courtesy Eastern Air Lines

Fig. 374. The worker is checking rate of climb instruments. Extreme accuracy is necessary for correct plane operation. Notice the special tools he must know how to use. What special aptitudes must he have to learn this job?

It is helpful, sometimes, to have others who are well acquainted with an individual rate him on his tact, sociability, and self-control under exciting conditions. A person is not always a good judge of himself in these respects.

3. If it is possible for one to do so, he can well afford to consult some competent specialist and request that he be given some of the well-established aptitude tests. A fairly large number of tests have been devised and are especially desirable not only because they have been shown really to measure aptitudes but also because they enable

one to see how he compares not merely with his friends and acquaintances, but with people in general over the country. Measures for linguistic and numerical aptitudes (the meanings of these terms were discussed above) are usually included in scholastic aptitude (mental ability) tests. There are also tests for spatial relations, social adjustment, and the like. A person can learn also whether or not his basic interests are like those held by persons who have succeeded in certain occupations. Tests of these kinds are technical instruments and should be used only by those who are trained to administer and to interpret them. More and more high schools are including on their staff individuals competent to give educational and vocational guidance. It is much to one's advantage to consult if possible with such a teacher or secure help from a neighboring college or university.

Many have aptitudes for a kind of work which they do not yet know how to do. Sometimes they are prevented from trying to do it because they fear that they cannot learn some of the things necessary. A boy might say, "I'd like to be an engineer but I just know I couldn't do the math." Perhaps he has never really tried to do mathematics, or when he did have a course, he didn't see how it could be of value to him. Some aptitudes, in other words, have not shown themselves because there has been no occasion to do so. If one wishes very much to do something and in other ways he seems capable, it may be well worth the time to take a course, get a job, or engage in an out-of-school activity just to see if the aptitude is not there.

In many aircraft manufacturing plants today, all entering employees are required to take tests of temperament, mental ability, and mechanical or clerical ability in addition to examinations of general health and physical efficiency.

Exercise 10. Regardless of whether or not you have had training in any of the following activities, try each one to see how well you can do it. Compare your performance with that of others in the class to determine if you are good, average, or fair in each.

a. Read a blueprint of a model airplane which shows two or more elevations.

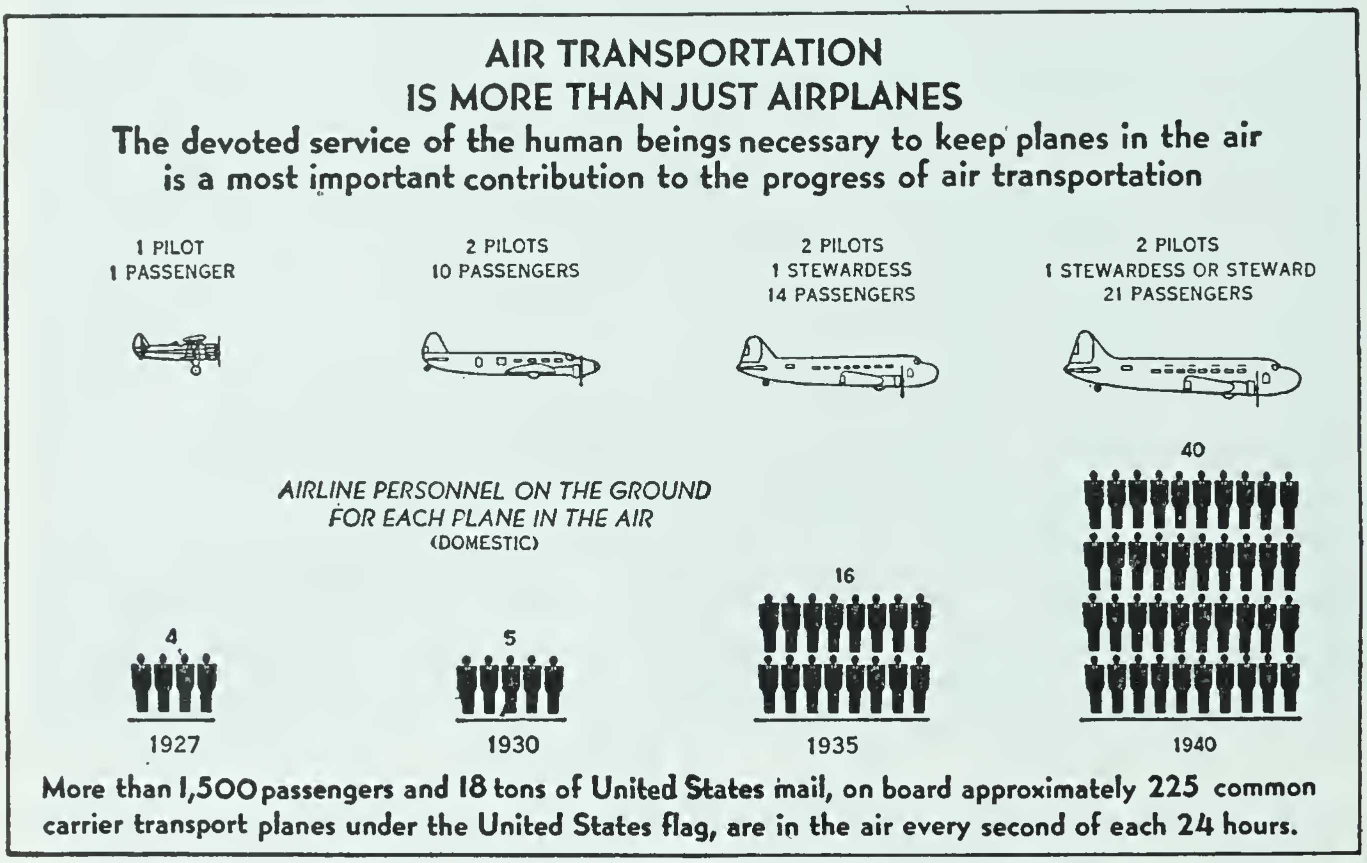
b. Take apart and reassemble a simple door lock.

c. Prepare a deck of fifty cards each with a name and telephone number copied at random from the various letters in the telephone directory. Shuffle the deck thoroughly. How quickly can you arrange this deck alphabetically? By number?

Have you had experiences or training which help to explain how well you did? If you did poorly on any of these, practice it or something like it once a day for a week or two and check your improvement. If you can do these things well, what type of work in aeronautics do you think you might try to learn?

Problem 6. How can one use information gained in this unit to avoid the mistakes commonly made in selecting a job?

As has been shown in this unit, the aviation industry is becoming so immense and embraces such a wide range of activities that a person with almost any ability or combinations of abilities may hopefully seek employment in it. It seems certain that some persons will be thrown out of work because of the new trend in transportation, but new jobs are being created, many of which are much like those which will be eliminated from other services. It is not implied that all who have been reading this book will want employment either directly or indirectly in aeronautical industry, but some of the particular qualifications for certain work have been suggested for the information of those who should want to try for a job or should have occasion to advise with others who do so wish.

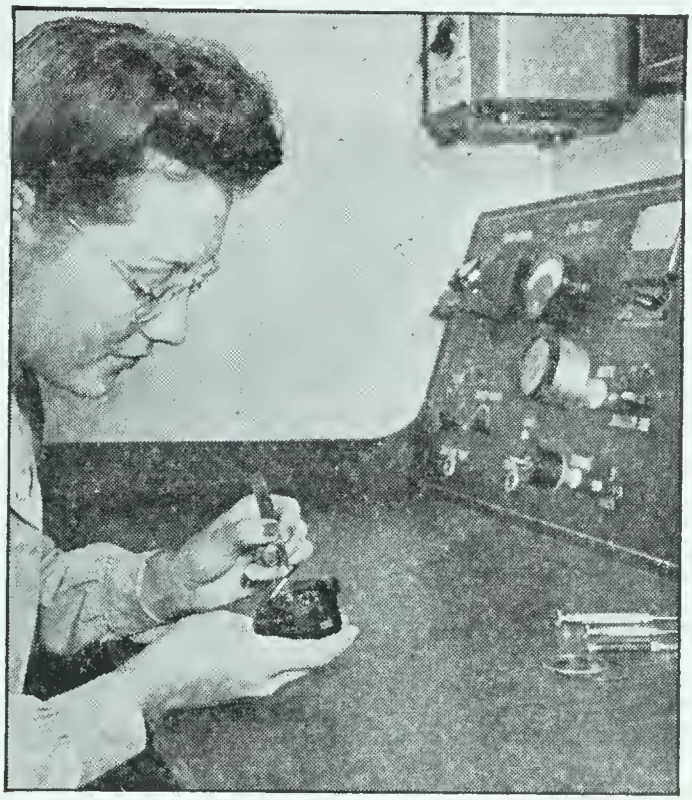


Courtesy Air Transport Association of America

Fig. 375. Aeronautics means more than just flying a plane.

There are a few other suggestions which may be of assistance to those who are concerned with the kind of work best suited to their abilities. Some of these may apply to other kinds of work as well as to aviation—the general principles will, of course, apply to any work.

One of the most common errors in planning for one's vocation is the failure to secure complete and accurate information about the vocation and about his abilities. A high school student thinks it would be great to be a pilot on an airliner. The pay is good, and everybody admires a pilot. The student is strong and healthy, he is a good football player, he can drive a car well. But has he stopped to think that he will have to get an extensive education in a course which involves mathematics, physics, meteorology, and similar technological subjects, and that then there will be several more years of working up through lesser positions? An airplane pilot wears a neat uniform—he appears much nattier than a railroad engineer, but let no one think that his is an easy job or one which can be secured by the "pull" of a friend or of an airline executive. It is truly a worthy ambition to be a pilot of a transport plane, but before one goes too far in his training he should be sure that he has what it takes in intelligence, finance, physique, stamina, and special aptitudes.

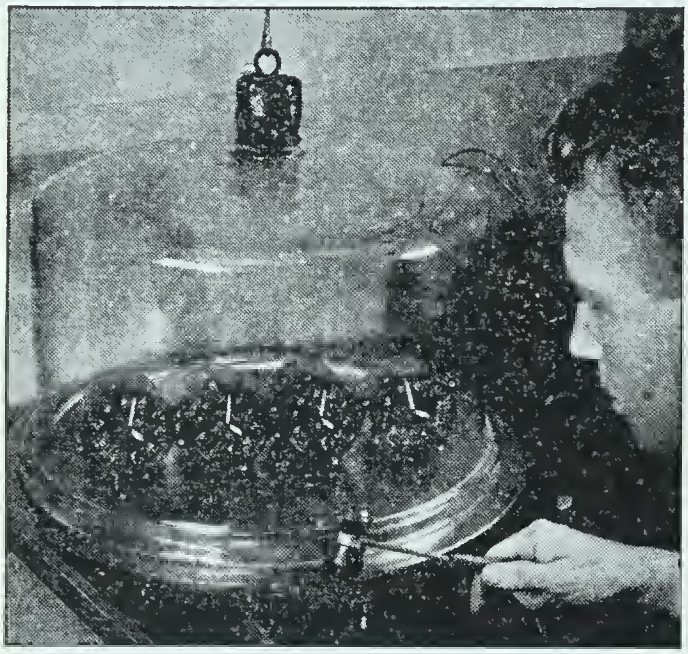


Courtesy Vega Aircraft Corporation

Fig. 376. Women find their place in all departments. Here a girl is checking and inspecting a delicate instrument. Lives depend upon the accuracy of her work, which requires knowledge of the instrument and skill with the hands. There is great satisfaction in a responsible job well done.

Almost every job has a certain glamour for somebody. The danger is that a person will see the glamour only. Some of the jobs with less glamour have values greater than those which look romantic. The waitress behind the counter of the airport cafe may be making more money than the stenographer she serves. A research man sometimes makes less money than a master mechanic. But it is not merely pay which determines the worth of a job. Any job is a good one which is suited to the abilities and temperament of the one employed in it. The point then is: Before starting to prepare himself for a particular kind of work, one should get all possible information about the abilities required to do it successfully, the cost of preparation, the working conditions, the satisfactions coming from it, and then analyze these in terms of his own abilities and his own personality.

Again some persons think they want to do or not to do certain kinds of work for reasons which are not really true or which are not on sound grounds. There may be family tradition for or against some occupation. That "all of our family have been pioneers, so of course, I will be a pioneer in the air" is not good reasoning. Nobody knows whether or not Christopher Columbus or Daniel Boone would have made a good flier. Neither is it relevant to know that "none of our people were ever any good with machinery." Whether or not a given person is mechanically minded will be proved by what he can do and what he likes—not by what was liked by his grandfather, who may never have heard of the present possibility. There are still some persons who believe that "white-collar" jobs give one a higher social standing and who will work for less money in order to wear the white collar—which costs more to launder when it does get soiled. In this age of machines, any work is respectable which is suited to the person doing it, and many prefer to work at "dirty" jobs in order to afford a change of clothes when the working hours are over.



Courtesy Eastern Air Lines

Fig. 377. Is this job as easy to do as it appears to be? The altimeters in the bell jar are undergoing final altitude tests. The worker taps the base with a rubber hammer to give the vibration necessary for correct reading. What other things must he know how to do to carry the heavy responsibilities of his job?

Some are afraid to fly, and their parents are afraid to have them do so. So, a few years ago, people were afraid to travel by train and later feared to go by automobile. There have been accidents by all means of travel, but today air travel is as safe as or safer than any other. And, of course, very few of those connected with aviation need to fly unless they wish.

There are those, too, who perhaps because they have been told that they should try to find work in line with their interests have the idea that the "right" job will be easy, or conversely, that the easy job is the right one. It should be remembered that any job that is worth while will require long, hard work both to prepare for and to perform. The right job will be more interesting to the doer than the wrong one, but it won't be easy. If one's work is easy, it is probably a sign that it is not worthy of his abilities.

In general a person should, when soliciting employment, apply for a specific job. He should be able to tell the personnel officer interviewing him why he thinks he is fitted for that job. He should be willing to take all tests and examinations suggested to prove his fitness, and he should be willing to start at the bottom of the ladder. He should have a fair idea, also, as to about how many rungs he will probably be able to climb.

Application Activities

Go through this unit and count the pictures where the view is of the interior or exterior of an airplane. Then count the number which were taken in factories making airplanes or airplane parts. What does the difference in numbers of workmen engaged suggest about employment in aeronautics?

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UNIT VIII

LIVING IN AN AIR AGE

EXPLORATORY ACTIVITIES

1. In what various ways has the airplane affected your life in the last ten years?

2. Do you see any very important relationship between the airplane and world geography? Explain.

3. In what special ways does the airplane serve mankind today?

4. To what extent has the government of the United States contributed to the air transport industry?

5. Do you consider the airplane to be an instrument of progress or destruction or both?

OVERVIEW

Scientists and inventors work in their laboratories and machinists in their shops that man may live in comfort and in luxury. Their achievements make possible the saving of life, of energy, and of time. Paradoxically, the same contributions are quite capable of doing the opposite, providing mankind becomes their slave.

In the preceding chapters you have become acquainted with the airplane. You have learned how it is made and how it functions, but that isn't enough. You must consider how to make the most valuable use of it. A gun is a weapon of mercy when it is fired to keep a mad dog from biting a child, but it is also a weapon of murder. A gun irresponsibly controlled is a danger; sanely controlled it is an aid to progress. So it is with the airplane in modern society.

The discussions of this unit attempt to introduce a little of the development of this gigantic instrument of speed. You will see how it shrinks the world but at the same time enriches man's experiences. You will see how it is putting a new emphasis upon global geography; how it is introducing new routes of commerce and how it is making neighbors of all nations. You will read of its record in war and consider its possibilities in peace.

Problem 1. How is the airplane changing our space-time concepts?

A New Age of Speed

The airplane ushers in a new age of speed. It was the age-old lure of material things which supplied the fifteenth-century pioneers of the western sea with a cause to prove their faith. It took Columbus and his crew more than two months to sail from Palos to San Salvador, a distance of approximately 4000 miles. But a new age in the history of the world had begun. The impact was great. The main routes of commerce shifted from the Mediterranean to the Atlantic. Business and financial supremacy passed from Italy and the German states to the Atlantic countries which controlled Indian and American trade. The Commercial Revolution was ushered in. Man's fixed concepts of space and time became either outmoded or obsolete. Those complacent souls who were content with the old days and the old ways were much like the king who marched to disaster with his crown over his eyes. Those people with vision rearranged their ideas. They would not fight against the future, for man had bounded the "boundless" sea.

In a later day and age came another revolution. Science was giving man machines. In 1825 George Stephenson, an English tinker, drawing heavily upon the ideas of Fulton, displayed his steam-propelled engine, capable of carrying passengers and freight at a maximum speed of eight miles per hour. Within a half-century the two oceans bordering the United States were tied together with bands of steel. Over mountain peaks and across trackless plains ran the transcontinental railroads. Again man was forced to revise his fixed concepts, for he had truly conquered the land.

1908 Wilbur and Orville Wright demonstrated to Europe their successful man-carrying flying machine. Within a few years there were wings over the Atlantic. By 1919 Albert C. Read made the first successful crossing, flying a distance of 3925 miles. In the same year John Alcock and Arthur Brown made the first non-stop flight. The world was entering upon a vast new age, for mankind had conquered the limitless air.

Economy in Distance and Time

The airplane economizes distance and time. There was a time when man was fearful of the natural world beyond his reach. That time is gone. Today he is master of land, sea, and air. Some say the world is shrinking. It is more exalting and perhaps more truthful to say that man is understanding and mastering the earth; that his horizons are widening. During the Middle Ages man lived in a very small world. Rarely did he go beyond the limits of the feudal estate or the local province. If he was so fortunate as to belong to the clergy or noble class, he might sometimes travel to the city or castle where the king resided. Although some people living today have traveled little more than did the mass of people of five or six centuries ago, the world is not hopelessly inaccessible. Perhaps it isn't that man's world is shrinking, but that he is acquainting himself with more of it. As crossing the "sea of darkness" and spanning a continent with rails taught those economic and industrial prophets of the future to revolutionize their geographical notions, just so have the aerial achievements of our twentieth century made necessary a revolution in our own geography to meet the needs of a rapidly changing world.

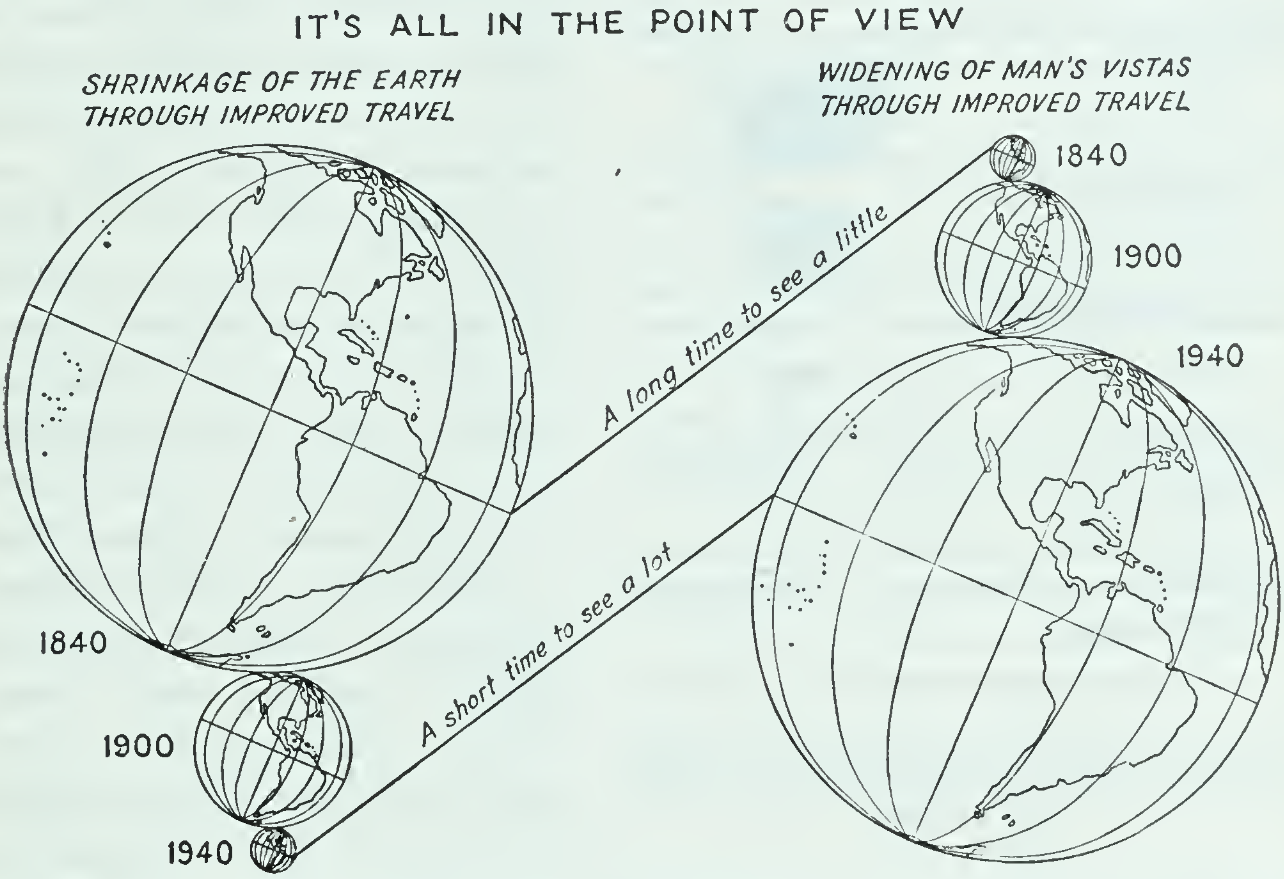

IT'S ALL IN THE POINT OF VIEW
SHRINKAGE OF THE EARTH THROUGH IMPROVED TRAVEL
WIDENING OF MAN'S VISTAS THROUGH IMPROVED TRAVEL
1840
1900
1940
A long time to see a little
A short time to see a lot
1840
1900
1940

Fig. 378 *a*. Man's experiences increase as improved transportation makes the world grow smaller.

The whole world measured in travel time is far more accessible today than was George Washington's United States or Napoleon's Europe. President Roosevelt attended an International Conference for Peace at Buenos Aires in 1936. He made the trip from Charleston, South Carolina, in two days' shorter time, including a stop in Brazil, than it took George Washington to travel from Mount Vernon to New York to be inaugurated President of the United States in 1789. In 1800 it took a stage coach four days in the best season to travel from New York to Boston. Today the same trip consumes little more than an hour. A century ago, weeks were required to cross the Atlantic from New York to Liverpool. Today modern ocean liners have reduced that time to approximately five days, while the airplane does it in less than a day. In 1858 it took the overland express twenty-four days to deliver a letter from St. Louis to San Francisco. Today transcontinental trains perform the same service in a little over two days, while the airliners whisk the letter to its destination between sunrise and sunset. In 1924 Lieutenant Maughan carried a copy of the morning *New York Times* to the Mayor of San Francisco before dusk. In the early sixteenth century Magellan's expedition battled against hunger and thirst, strange peoples, and uncharted seas in its effort to sail around the globe. After three years of struggle a remnant of the expedition accomplished that end. Our age has witnessed the encircling of the globe by United States army fliers in 1924, covering a distance of 27,553 miles in 175 days. The flying time was 351 hours. Again in 1929 the Graf Zeppelin made a global flight beginning and ending in Lakehurst, New Jersey, and covering a distance of 20,000 miles in a few hours over twenty-one days. Howard Hughes completed his polar circumnavigation of the globe in a little under four days. To be sure the distances covered in these aerial achievements do not approach the mileage covered by Magellan's expedition, but the objective—encircling the globe—was the same.

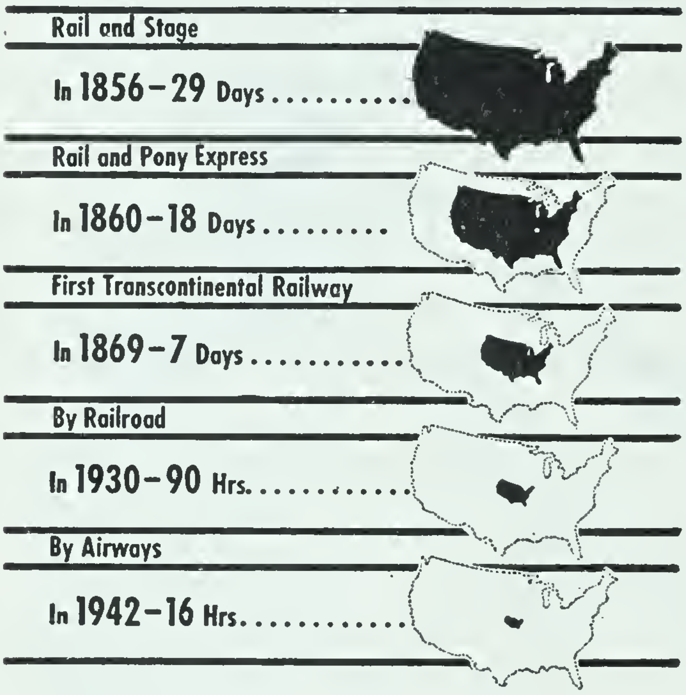


Fig. 378 *b*. Improved coast-to-coast transportation makes the United States smaller and smaller.

All of this evidence indicates that we cannot think of distance in terms of miles. Now we must think of it in terms of time. American schools are still inclined to teach that Germany is 4000 miles away from us, while German schools are teaching their children that the United States is fifteen hours away. "In another year," they are likely to say, "it will be only ten." In these days of *blitzkriegs,* one cannot afford to be geographically illiterate. We are told that modern airliners are capable of speeds as great as 300 miles per hour. On this basis it would be possible to fly from San Francisco to Singapore in twenty-nine hours. The fastest sea travel for that journey at present is twenty-two days. On the same basis, New York and Capetown would be twenty-six hours instead of twenty-five days apart. As man's techniques for overcoming distance improve, a mile or a kilometer takes on new significance. Therefore these figures are in no way final but are quoted primarily to show the growth and the spirit of the age in which we live.

The shortest distance between two points on the earth's surface is a curved line because the earth is a sphere. This line lies along the arc of a great circle. All circles upon the earth which divide it into two equal parts are great circles. Great circles need not follow the same pattern as the meridians, but may be at any angle to these providing they divide the earth in half. A parallel is not a great circle because it divides the earth into unequal parts. Airplanes usually fly great circles since they are not, as a general rule, handicapped by surface barriers. By flying the great circles they reduce the actual mileage as well as the time. To reach Moscow from New York one would not fly eastward across the Atlantic but northward, passing near the north pole. The direct route from Tokyo to the Panama Canal is by way of the Aleutian Islands, Seattle, Denver, and the Gulf of Mexico. From Seattle to Calcutta is only 7,300 miles by air line as compared to the 12,000 miles by ocean route. The distances have meaning only in relation to time.

Sense of Remoteness Eliminated

The airplane helps to banish our notion of remoteness. We have seen how the airplane has moved us next door to most of the nations of the earth. But we are still inclined to retain a sense of remoteness which is characteristic of our traditional habits of thought. In spite of Pearl Harbor and gigantic preparations for global war, there exists a complacency based upon geographical illusion. Illusions about this world can be dangerous. Asia may seem remote. Actually Bering Strait separates Asia from North America by less than fifty miles of water, a fact of great strategic importance. The Azores, which Columbus left as he faced the shoreless seas, had become almost legendary until an air age brought them to public attention. They are a thousand miles closer to New York than New York is to San Francisco. Which European nations control African colonies has been of little concern to most Americans. But if those colonies should fall into enemy hands, it would vastly concern our Pan-American relations, since the United States is farther away from Brazil than Africa is.

The Good Neighbor Policy is making us conscious of the Latin American people who have occupied the same hemisphere with us for more than three centuries. As we consult our maps to learn more about these neighbors to the south, our first surprise usually comes with the realization that virtually all of South America lies east of the United States. If you extend a line straight southward from Detroit, Michigan, it will just clear the most westerly point of the Peruvian coast. This explains why Rio de Janeiro and Buenos Aires are closer to London and Berlin in travel time than they are to New York City. The size of South America gives us our next surprise. A land which has been too obscure to engage the interest of most North Americans turns out to be almost three times the size of the United States. Brazil alone is as large as our forty-eight states plus another state the size of Texas. Mexico is one-fourth as large as the United States, while more or less unfamiliar Nicaragua is almost as large as England. These illusions may be due to the difference in population—the total of all Latin American states amounting to about one hundred and twenty million souls—or to the facts that we have the same name, we live in the same hemisphere, and we are connected by land.

This war for survival is destroying many of our geographical notions en masse. The nearest enemy territory to our own is a Japanese island in the Kurile group just south of the Russian peninsula Kamchatka. It is a matter of minutes from that point to the Aleutian Islands off the Alaskan coast. Detroit, one of the most important centers in this arsenal of democracy, may seem to be out of reach of bombs from Europe. But if the Norwegian city of Trondheim should be used as a jumping-off point for an enemy power, Detroit could be bombed as easily as Washington, D. C. Through the channels of the war we are suddenly becoming conscious of such names as Martinique, Madagascar, Sarawak, Celebes, Salween, and Sevastopol. We are beginning to think in terms of world strategy instead of local or regional strategy. We are suddenly becoming aware that we live on a sphere instead of in a hemisphere.

Africa, that "remote" continent strangely familiar through the conquest of Carthage, the exploration of David Livingstone, the stories of Trader Horn or about Timbuktu, is brought uncomfortably close to our attention. General Erich Ludendorf of Germany said during the lull between the first and second world wars, "The fate of the next war may be decided in Africa." And when we consider Suez and Libya and the French and British control of Africa, the statement might well be true. The name Dakar was virtually unknown until this war. Dakar was far from the tourist centers of Africa. For a long time it was even ignored as a stopping place on the highway of trade. But suddenly that port on the tip of the bulge of Africa became the outpost of two continents. It faces the bulge on the east coast of South America. The distance between this capital of French West Africa and the port of Natal in Brazil is 1620 nautical miles. Today the airplane has placed Dakar within five hours' reach of South America. Dakar is closer to the western hemisphere than are Iceland, which we have already garrisoned, or Honolulu. While the present status of Dakar is precarious, in enemy hands it could become the spearhead of an attack. The significance of this fact in relation to the new world is obvious.

The nearness of Dakar to the western hemisphere is not the only reason for its being strategic. It is at present situated at the junction of two of the most heavily traveled sea lanes, one linking Europe with Latin America, the other connecting Europe with the middle and Far East because of the routing of traffic around the Cape of Good Hope. Its strategic position is intensified by the fact that within Dakar's own elbow room lie the Azores, Madeira, the Canaries, Cape Verde, islands now in Spanish and Portuguese hands. This is of vital importance in the battle of the Atlantic from the standpoint of both sea and air power.

Asia—that far-away land of yellow and brown peoples, of rickshas and houseboats far removed from roadsters or trailer houses; that land of magnificent handwork, of fine silk, a far cry from mass production–suddenly becomes a part of "our" world. The ambitions of the inhabitants of the land of the Rising Sun brought it particularly to our attention. Since Pearl Harbor, some of our airmen have had a bird's eye view of Tokyo. The United States is fighting particularly to keep the Pacific from falling into enemy hands. Because Japan stands in the way of freedom of the Pacific, nations must fight. The airplane is an ever-increasing force in the struggle to keep the Pacific free. When this battle is won, erroneous notions of the Pacific peoples may disappear.

Columbus' fundamental error was underestimation of the size of the earth. Such an error today, in reverse, could bring disaster upon civilization. "Those of us who lack basic familiarity with continents, oceans, distances, climates, mountain chains, deserts, jungle, sea routes, air routes, etc.," says the editor of the *Mercury,* "must grope through current events like men with blurred sight."

The Importance of Maps

The airplane is placing a new emphasis on maps. Recorded history indicates that certain ideas and particular achievements have given impetus to man's progress on earth. They have caused him to change his religion, his philosophy, his economy, and even his concept of the earth itself. With each changing geographical concept came the problem of portraying cartographically (by charts) ideas that were in men's minds. When Columbus sailed westward completing a transoceanic voyage, the belief in a world centered about the Mediterranean was obviously doomed. While Columbus accepted the map of Ptolemy, who believed that the earth was a sphere, and who represented the best in Greek cartography, the typical map of the time portrayed a disk-like earth which had satisfied the Romans. By 1522 the remnant of Magellan's proud fleet had circumnavigated the globe, proving Ptolemy's belief in a sphere, but discounting his notion of its size.

It was not long until Mercator, a Dutch map maker of the sixteenth century, liberated cartography from the influence of Ptolemy. Mercator's cylindrical projection of horizontal parallels and vertical meridians was highly adaptable to ocean navigation in the day of sailing vessels. It suffered little competition until the latter part of the eighteenth century when Lambert's conic projection was introduced.

The nineteenth century brought the Industrial Revolution with its advent of power-driven machines. This was a second great factor influencing man's concepts and affecting his charting of the pattern of the earth. New lanes of commerce were developed. Speedy power-driven vessels plied the seas on regular routes and on regular schedules. It soon followed that technology had equipped ocean-going vessels for direct travel across the ocean basins instead of sailing from island to island or hugging the shore. By the same token, railroads and highways were built across the plains and through the mountains, under rivers and over bays until land transportation routes have formed a veritable network throughout the length and breadth of the continents. These modern inventions, which widened man's horizons, rendered inadequate the maps of the time.

Map makers began a new search for a solution to their age-old dilemma—charting on a flat surface a sphere or curved areas. The more practical-minded wished to compromise the various projections in order to distort neither the shape nor the scale to any great extent. As a result of their efforts a variety of the azimuthal (plane) type of map was produced. In this map the parallels of latitude and the meridians are indicated by curved lines. These projections have more satisfactorily met the needs of a power age on land and sea. The most satisfactory result of this new effort, according to some experts, was the equal-area ocean-basin map. This map does not show the world as a cylinder at all. Instead it shows three great ocean basins—the Atlantic, the Pacific, and the Indian. The continents become mere rims of land bordering the ocean basins. There is no implication of an eastern and western hemisphere. This map is valuable in showing sea routes to a better advantage. It is accurate to the extent that any region portrayed on the map has the same area it would have on a globe of the same scale.

In 1903 there occurred at Kitty Hawk, North Carolina, the realization of mankind's effort to fly. This is a third great factor influencing man's concept of the earth and his system of charting the concept. We entered what has been called a three-dimensional world. Since the north polar region offers short-cuts by air between the old and the new worlds, maps are now being projected which place the north pole at the center. (See Fig. 379.) This is another position of the azimuthal projection. Around this "hub" the Arctic Circle is drawn. Encircling that, still farther away is the Tropic of Cancer. Finally, out near the periphery of the map, lies a great circle, the equator. The meridians radiate from the poles like the spokes in a wheel. The portions beyond the equator are greatly distorted. The chief value of this map lies in its portrayal of distance relations among nations bordering the regions of the north pole.

It is not maintained that the polar projection will depose all other recent and useful maps. It is upheld rather as an additional graphic device for enhancing our understanding of new world vistas through the avenues of air technology. It is upheld as a means of sharpening our sensitivity to global rather than local geography.

President Roosevelt emphasized the importance of maps and their implication in his address of February 23, 1942. He pointed out the need of a global point of view in our present state of affairs when he said: "This war is a new kind of war. It is different from all other wars of the past not only in its methods and weapons, but also in its geography. It is warfare in terms of every continent, every island, every sea, every air lane in the world. . . . There are those who still think in terms of the sailing ships. They advise us to take our warships and our planes and our merchant ships into our own home waters and concentrate solely on last-ditch defense. Look at your map. Look

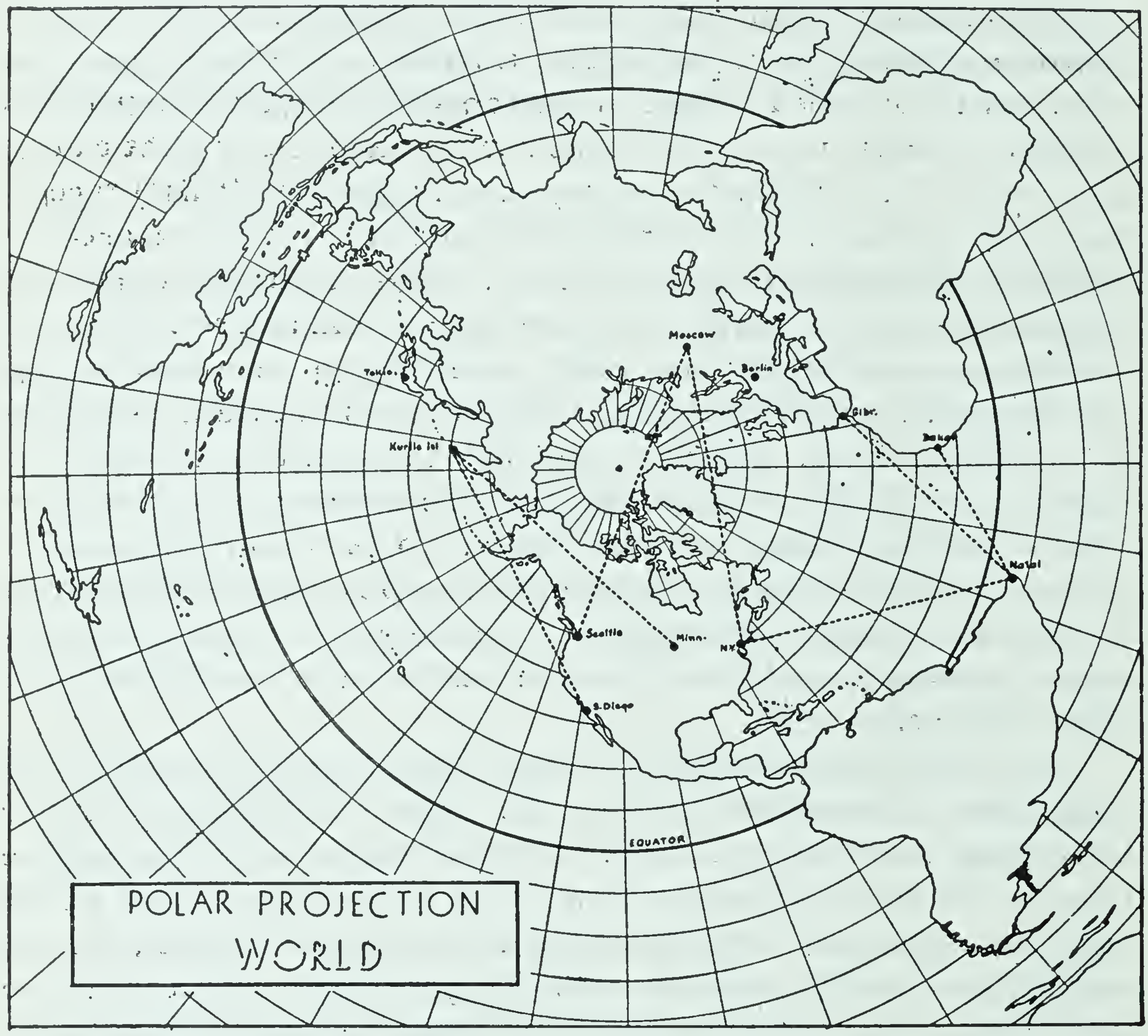
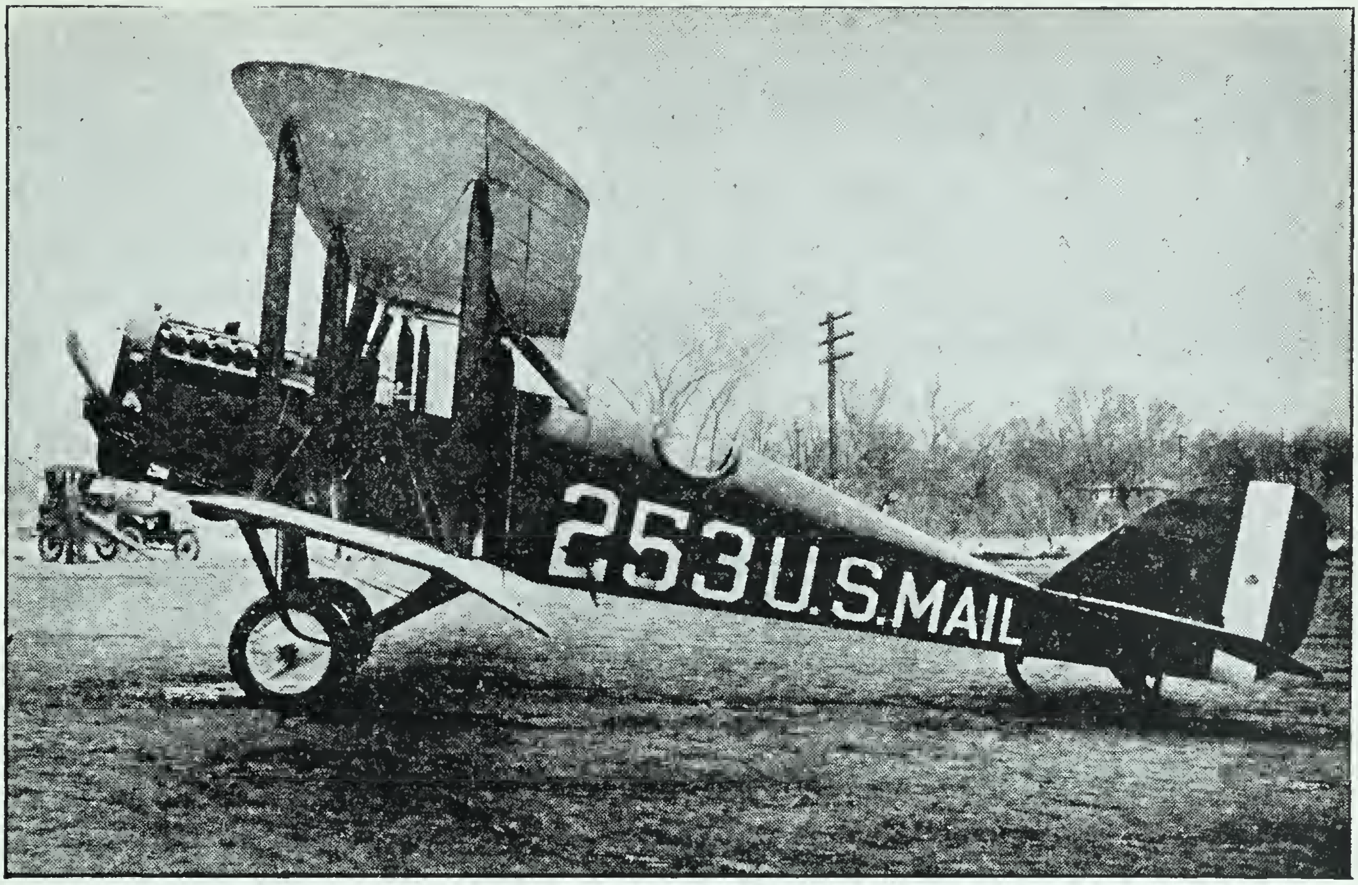
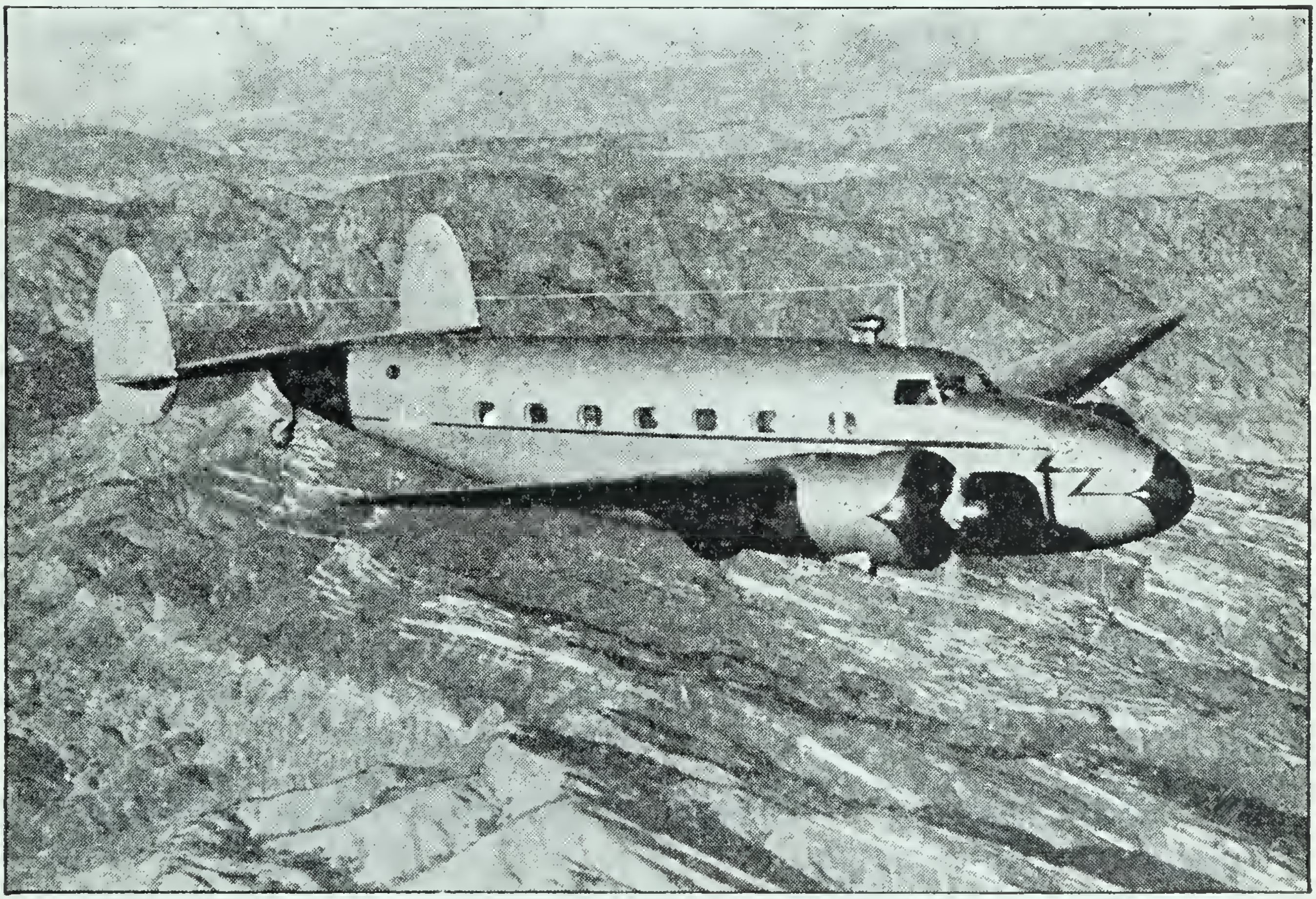


Fig. 379. The polar projection of the world is increasing in importance with the use of the airplane.



Courtesy United Air Lines



Courtesy National Airways, Inc.

Fig. 380. The difference in twenty years

at the vast area of China with its millions of fighting men. Look at the vast area of Russia with its powerful armies and proven military might. Look at the British Isles, Australia, New Zealand, the Dutch Indies, India, the Near East, and the continent of Africa with its resources of raw materials and of people, determined to resist Axis domination. Look at North America, Central America, and South America. It is obvious what would happen if all these great reservoirs of power were cut off from each other by the enemy or by self-imposed isolation."

Exercise 1. By using a taut string to find the shortest distance between two points on the globe, determine:

a. The shortest route from New York to Moscow.

b. The shortest route from Minneapolis to Calcutta.

c. Whether St. Johns in Newfoundland or New York City is closer to Dakar.

d. The difference in distance between New York and the Black Sea and New York and Buenos Aires.

e. The difference in distance between the northern extremities of Japan and Alaska, and San Francisco and Alaska.

f. Which is farther from San Francisco, Cape Horn or Brisbane, Australia.

Exercise 2. Select some comparisons of your own after measuring on a globe and try them on your classmates.

Exercise 3. On a map of the world show by variation of lines or color (1) the routes of travel, (2) the mode of travel, and (3) the time consumed in each of the following cases:

a. Columbus' journey from Palos to San Salvador, 1492.

b. Vasco da Gama's journey from Portugal to India, 1497.

c. The journey of Magellan's expedition around the world, 1519-1521.

d. The record trip of the *Cutty Sark* in tea trade with the Orient, 1868-1872.

e. The trip of the China Clipper from California to the Philippines, 1935.

f. The journey of Alcock and Brown from Newfoundland to Ireland, 1919.

g. The journey of Lieutenant Russell L. Maughan from New York to San Francisco, 1924.

h. The journey of Amelia Earhart from Mexico City to Newark, New Jersey, 1935.

i. The journey of Wiley Post and Harold Gatty around the world in the *Winnie Mae,* 1931.

Add any other famous ocean, land, or air journeys to the map you care to.

Exercise 4. Make original cartoons or pictographs illustrating materials in or prompted by the text. These suggestions may help you to think of others:

a. Pictograph showing the shrinking of the Atlantic through improved travel.

b. Pictograph showing the shrinking of the Pacific through improved travel.

Exercise 5. Make a list of all the geographic terms you can find appearing in the newspapers or that you hear in connection with the news. Locate them on the globe and tell why some of them are in strategic locations from the standpoint of military activity.

Exercise 6. Make an oral or written report on one or more of the following topics, or select one of your own:

a. The First Flight around the World (1924).
b. The First Polar Flight (1925).
c. Byrd's Dash to the South Pole.
d. Amy Johnson's Solo Flight from London to Capetown.
e. Macmillan's Flight in Quest of a New Polar Land.
f. The Ocean Clippers.
g. Clippers of the Air.

Problem 2. How is the airplane growing in commercial importance?

AIRMAIL

When regular transcontinental airmail service began in the fall of 1920, businessmen were still inclined to be disinterested since very little time was gained over that of the trains. Night flying had to be the answer. So night flying was inaugurated in 1921. There were no radio beams, no weather stations, no lighted airways. But two decades later these were plentiful and efficient, and widespread airmail service was in common use.

AIR PASSENGER TRANSPORT

In Europe passenger-carrying service was the fundamental goal of air transport. In America the finest airmail service in the world was developed because of its initial priority. But passenger service was not completely discounted. The growth of passenger transport in air cannot be appreciated without a glance or two at its beginnings. It had its inception in the city of Paris in 1870 when the Parisians, besieged for 127 days, sent sixty-four balloons carrying eighty-eight passengers and 4,000,000 letters to the outside world. In 1911 five Zeppelins, Germany's lighter-than-air craft, operated for two years between local cities. They carried over 34,000 passengers 107,000 miles with no loss of life. In the same year Louis Bréquet boasted that he had flown an airplane carrying twelve passengers. The spirit of youth was the essence of this experiment, for the passengers were twelve little boys.

Courtesy Eastern Air Lines

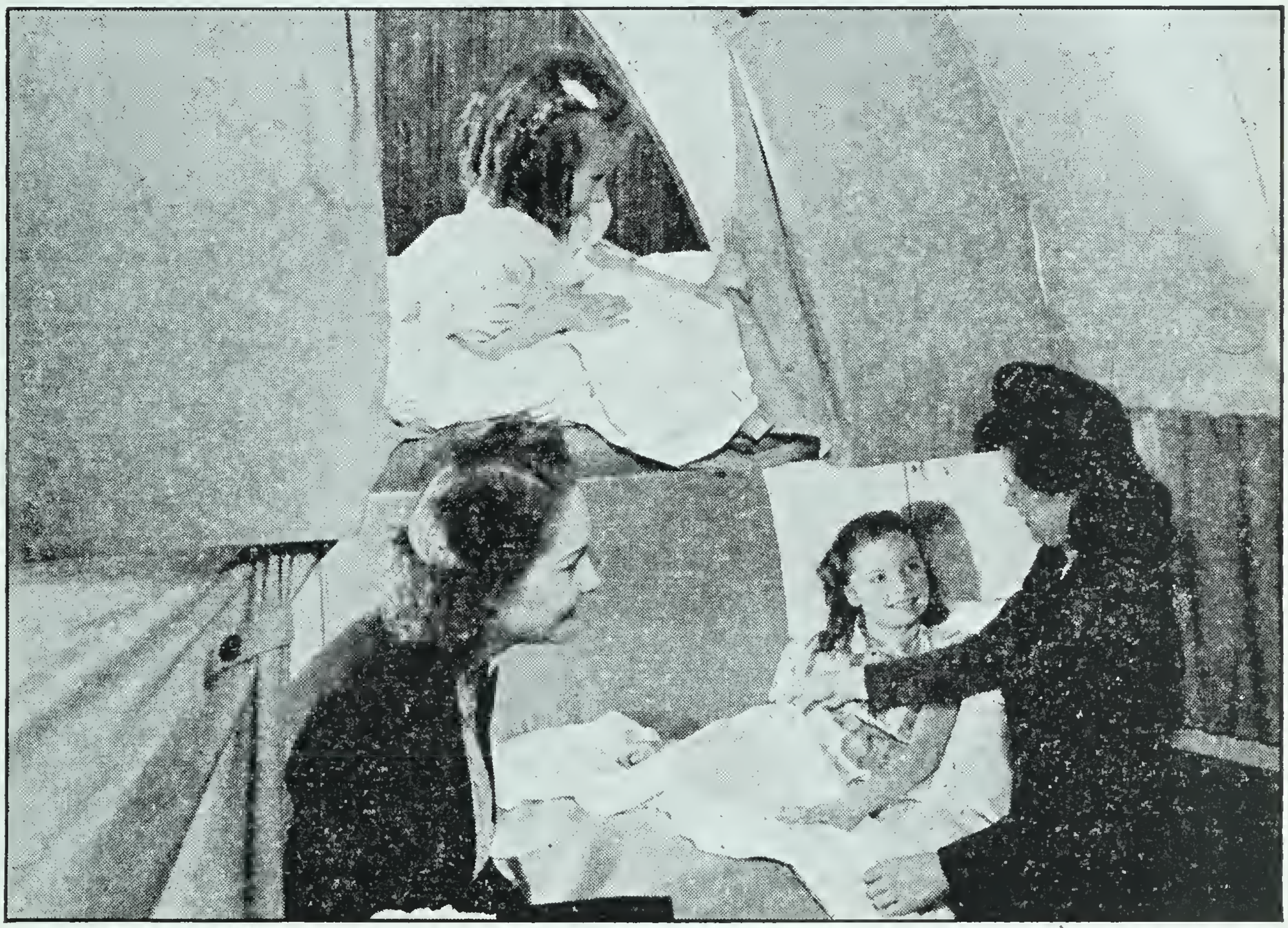
Fig. 381. Modern airliners provide comfort, speed, safety, and enjoyment

The first scheduled passenger line in the United States was an aerial ferry across the bay between Tampa and St. Petersburg, Florida. The service began on January 1, 1914, and shuttled passengers between the two cities until the tourist season ended. In the spring the Tampa line disappeared. The first airline passenger agency in the history of American aviation was opened by the Aero Limited Company which carried passengers from Miami to Nassau in the Bahamas. The company was later absorbed by the Aeromarine Company which boasted of having carried 30,000 passengers safely more than two million miles in four and a half years. When the United States and Cuba withdrew mail contracts, the line to Caribbean islands was discontinued. Aeromarine had pointed the way, yet it was obvious that well-managed lines could not pay dividends without mail payments.

Most lines having mail contracts recognized that as their chief source of revenue and did not bother to install seats for passenger service. In an emergency passengers might be tucked in with the mail sacks. One airline reported taking a newly married couple on a

500-mile wedding trip for a thousand dollars. In these first years of passenger service it cost two hundred dollars to fly from Chicago to New York.

Henry Ford was the first to combine regular passenger service with airmail transport. Western Air Express through a Guggenheim Fund grant experimented with passenger traffic in 1927 and returned the loan from the company's earnings within two years. Colonial Air Transport inaugurated night passenger service between New York and Boston in April, 1927. In spite of these experiments airmail still held the place of honor in terms of dividends.

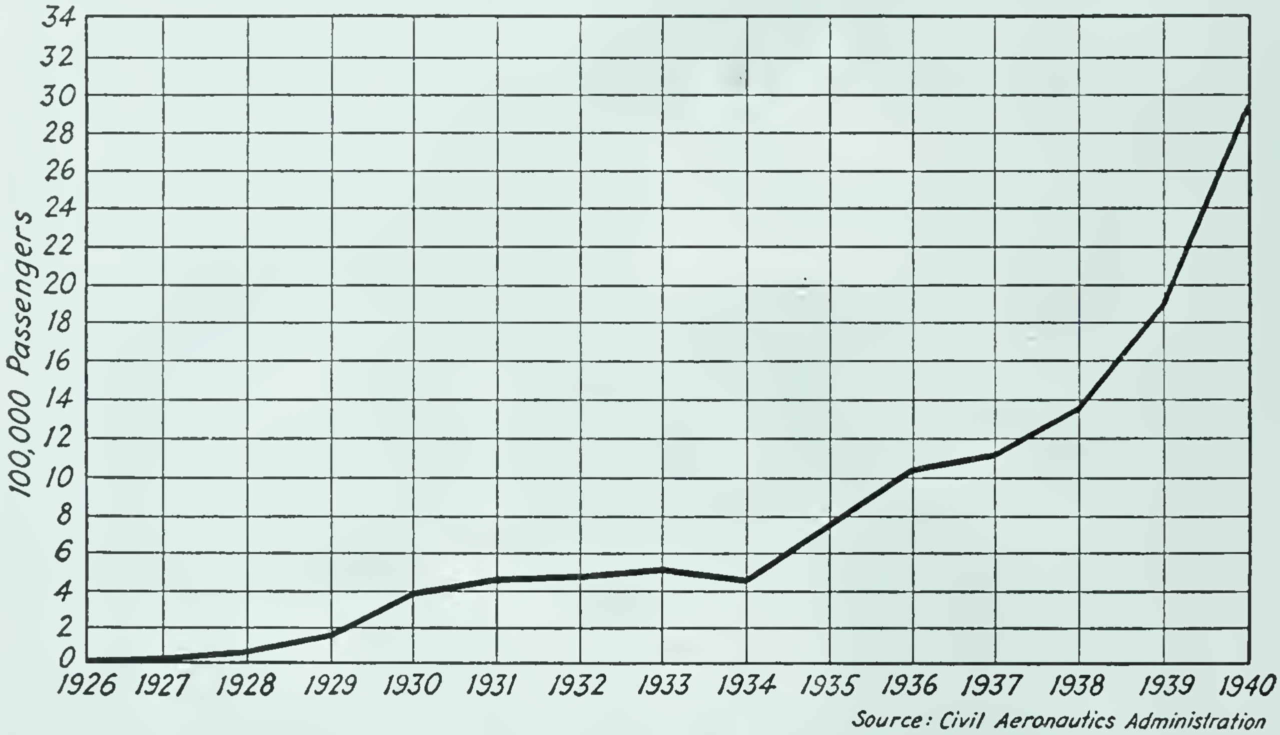


Courtesy Transcontinental and Western Air, Inc.

Fig. 382. Mother and children have no fear as they are whisked through the night in a modern airliner

There were a few operators without mail contracts who attempted passenger service exclusively. They were known as Independents. One of the most successful of these was the Standard Air Lines which had its beginning in the daring of the "Thirteen Black Cats," Hollywood stunt fliers. The Standard attributed its success to the patronage of movie people who wished to fly to their hideouts in Arizona.

With the merging of air transport companies into great consolidations of routes and capital, passenger transport came of age. The underlying reason for the expansion of passenger transport can be found in terms of speed. Passenger flying time from coast to coast began in 1929 with forty-eight hours. By 1930 it had dropped to thirty-six hours. Two years later it was cut to just under twenty-five hours. At the time of this writing flying time across the continent is approximately 16 hours. With rates and fear rapidly diminishing, and comfort, safety, and speed increasing, it would be difficult to prophesy the expansion of passenger transport in the future, but the trends are clear.



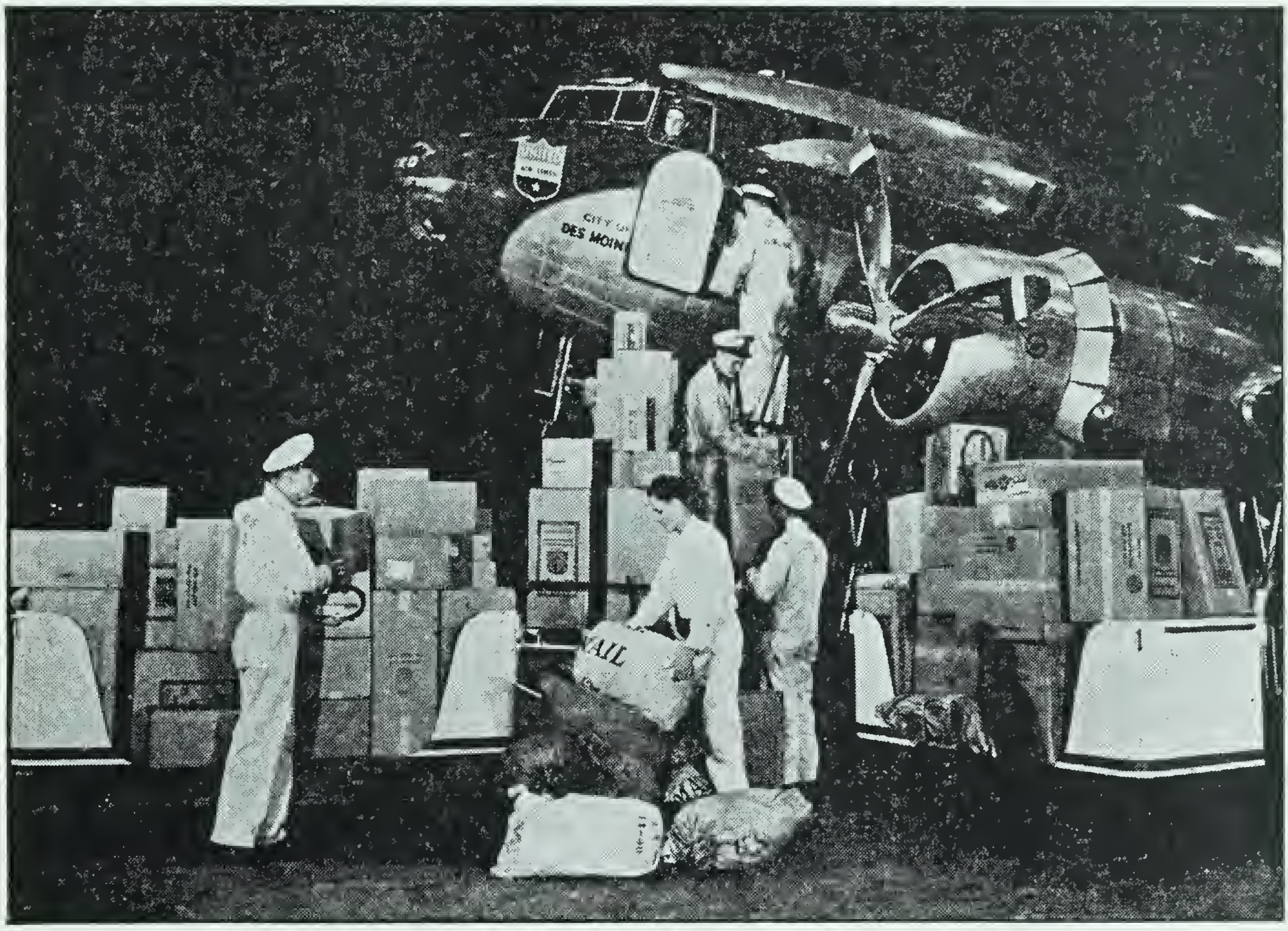
Source: Civil Aeronautics Administration

Fig. 383. Passengers carried by domestic air lines. (Numbers are in hundreds of thousands.)

AIR EXPRESS

Cargo service is the most recent development of the air transport industry. In fact, little was generally heard about cargo planes until the war brought their possibilities and need to public attention. In the earliest days of aviation it was thought that transportation of property would precede transportation of passengers, but those thoughts were amiss as developments showed.

The year 1919 marks the beginning of experimentation with transport of cargo by air. The first regular service began with Henry Ford's experiment in shipping automobile and airplane parts from Detroit to Chicago, and from Buffalo to Detroit between 1925 and 1932. The experiment was striking in that it was a purely private operation and the results compared favorably with the performances of common carriers during the same period. The line was discontinued in 1932 when Ford ceased to manufacture airplanes. Other companies attempted regular and exclusive air-express transport only to conclude that express must be coupled with airmail and passenger service. In this form air-express service was available to eighty-two cities in 1929.



Courtesy United Air Lines

Fig. 384. Planes carry heavy cargoes.

By 1931 some of the major airlines began to take an active interest in air express. Transcontinental and Western Air worked out a coördination system with the Greyhound Bus Company for carrying off-line packages. In 1932 the Air Express corporation was formed to provide express service between New York and Los Angeles but was discontinued after two months' trial. On the heels of this an interline company called General Air Express was organized to enable the companies to act as a unit in the solicitation and handling of air express. The rates were uniform throughout the entire system. The General Air Express began with seven major airlines which flew 16,000 route miles per day. They served most of the major cities of the nation and competed with the Railway Express Agency so effectively that the railway agency's rates were forced down. In 1934 the Railway Express Agency signed contracts with Pan American Airways thus facilitating service between the United States and the West Indies, Central, and South America, and later with the Far East and Europe. Through this service any point in South America could be reached within seven days.

The General Air Express was discontinued in 1935 when the airlines decided it would be more to their advantage to form a kind of alliance with the Railway Express. It would also be an advantage to the Railway Express as competition between the companies would be eliminated. Thereupon contracts were arranged between the individual airlines and the Railway Express. Each contract had the same terms, and all airlines were to operate in the same relationship to the Railway Express Agency. This is essentially the arrangement which exists at the present.

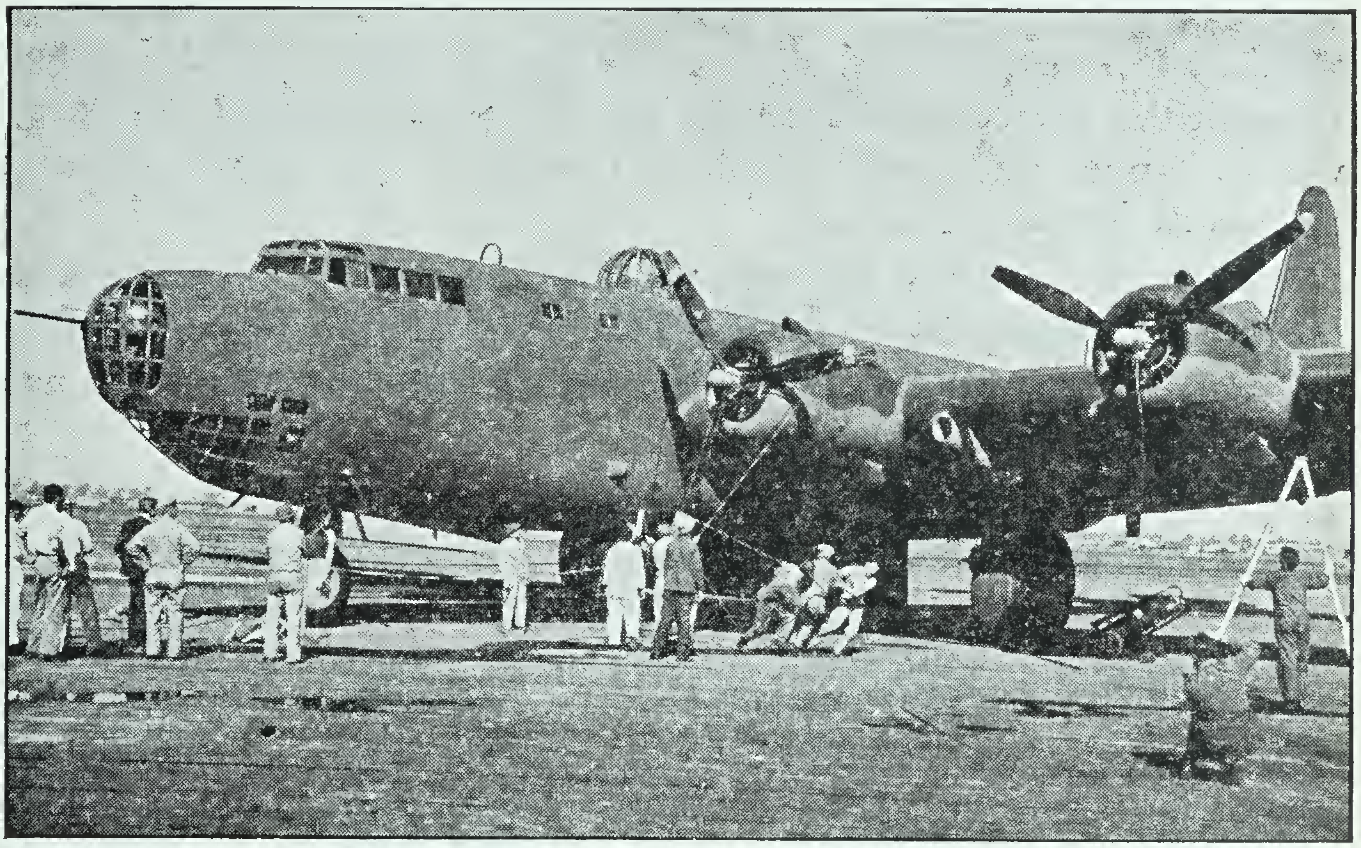
AIR FREIGHT

The possibilities of air cargo are being greatly exploited as a result of the war. The development of this phase of aviation is probably much greater than available information indicates. Facts and figures which are published indicate an enormous growth. Railway Express reported an increase in shipment of heavy cargo of 108 per cent for the month of April, 1941, over the corresponding month, 1939. United Air Lines reported a 48 per cent increase in 1941 over 1940. Government figures of September 30, 1941, showed 17,200,000 pounds transported. United reported air shipments to and from Chicago in 1940 amounting to 1,500,000 pounds at rates six or seven times greater than railway express. It was reported authentically that by 1940 the Army Air Corps was carrying more cargo than all the domestic airlines put together. Naval Air Transport service was successfully organized soon after the Army Air Corps.

Many giant cargo machines are being designed and produced. One of the leading aircraft manufacturers stated, "My company already has plans for a 250,000-pound commercial air vessel, and our studies show that no technical considerations limit the size of airplanes that can be built. The only limit is the amount of pay loads available per trip. We should be able to build 200,000-pound airplanes in a few years." Already designs are completed for 250,000-

pound aircraft which will fly from New York to London, non-stop in thirteen hours, carrying one hundred passengers, 8,000 pounds of baggage, and 25,000 pounds of mail, cargo, and express.

The two largest present aircraft, the first successfully flown and the other being tested, are the Douglas B-19 and the Mars (Martin plane). The B-19 is 212 feet in span, weighs 83,000 pounds empty, has a maximum overloaded weight of 164,000 pounds which it can lift into the air and with which it can then cruise at a speed of nearly 200 m.p.h. with a range of over 7,000 miles.[1] The Mars is a seaplane of 42,000 horsepower, a little under the B-19 in speed and weight, but can carry a heavier load.[2] Loening, pioneer aeronautical engineer, says the Mars will be able to deliver goods from the United States to the Red Sea in the same amount annually as an 11,000-ton, ten-mile-an-hour ship and would eliminate the submarine menace. Curtis of the Curtis-Wright Corporation announced in May, 1942 its C-46 all metal monoplane of 50,000 pounds gross weight which will carry armed infantry, field artillery, and mechanized equipment. Without cargo it could fly non-stop to Australia. The Lockheed Constellation is a supertransport with engines which develop about 42,000 horse-



Courtesy Douglas Aircraft

Fig. 385. Guardian of a hemisphere

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[1] Edward Warner, "What Airplanes Can Do," *Foreign Affairs,* January 1942.

power, a 5,000-mile range, and a cruising speed of 300 miles an hour. It is believed that in the near future cargo planes will be produced which will weigh eighty tons, will fly 300 miles an hour, and have a range of 7,500 miles, a distance equivalent to that between California and Australia.

Space does not permit more discussion of these great accomplishments. Rapidly changing events would render as understatements much that might be said, but the trend is clear. If the completion of the Union Pacific Railroad opened up a new trade between the United States and the Far East, how much more shall we be able to supply the human needs of over 400,000,000 people of the Orient through the efficient and extensive service of cargo planes! Resources will be tapped and markets may be developed to a degree of which the world has not dreamed.

Exercise 7. Make a graph showing the number of plane-miles flown with airmail between 1926-1940. At the left indicate the mileage in terms of millions beginning with 0 and progressing by tens to 70. Use the following data:

	Plane-miles		Plane-miles
1925–1926	396,345	1933–1934	29,111,474
1926–1927	2,805,781	1934–1935	31,148,693
1927–1928	5,585,224	1935–1936	38,700,643
1928–1929	10,212,511	1936–1937	39,958,771
1929–1930	14,939,468	1937–1938	46,166,162
1930–1931	21,381,858	1938–1939	52,087,028
1931–1932	32,202,170	1939–1940	59,177,525
1932–1933	34,909,811	1940–1941	74,297,154

Can you explain the trends indicated on your graph in terms of the progress of airmail?

Exercise 8. Make a graph showing the *airmail postage rates* since 1926. Write to the Civil Aeronautics Board, Washington, D. C. for information or consult your teacher for suggestions.

Exercise 9. Make a graph showing the average *air passenger fare per mile* beginning with 1926. Consult your teacher for references.

Exercise 10. Prepare debates, panel discussions, or floor talks on one or more of the following topics:

a. Resolved, that the air transport industry should be thoroughly regulated by the Government.

b. Resolved, that travel by air is as safe as travel by rail.

c. Resolved, that the rapid growth in air transportation is dangerous to our social well-being.

Exercise 11. Make an oral or written report on one or more of the following topics:

a. The Present Air Traffic Rules

b. How Airplanes Are Licensed and Inspected

c. The Newest Models of Airplanes and What They Will Do

d. The Government's Part in the Development of Air Transportation as Compared with Its Part in Railroad Development

e. A Comparison of the Civil Aeronautics Act with the Interstate Commerce Act

Problem 3. In what special ways does the airplane serve us today and guide us toward tomorrow?

Miscellaneous Uses of the Airplane

The airplane is becoming a jack-of-all trades as well as master-of-many. The primary uses of airplanes today are for military purposes; for the transport of mail, passengers, and cargo on regular lines; for sightseeing; and for private travel. There are, however, many other ways in which they are employed. Some of these require special design and equipment, and some are merely special uses to which private and commercial planes may be put. No description of these services can be complete because new uses are being found continually. Something of the variety of uses will be indicated here. For example, the airplane has become exceedingly valuable as a means of exploration, both in new areas and in the rediscovery of things which have been lost in old countries. Aviators flying over areas in South and Central America not only were able to get the general "lay of the land" and to locate the courses of rivers; they discovered the ruins of prehistoric cities, the archaeological studies of which have added new chapters to the history of western civilization. Polar flights made possible at last the accurate mapping of the arctic and antarctic regions. Mt. Everest has not yet been scaled, but it has been seen from above.

A few years ago an aerial photograph of the Alleghenies was made which showed what was later found to be the location of the Mason and Dixon line. Fliers over coastal areas have located submerged rocks and reefs as well as, occasionally, sunken boats. Long-abandoned Western pioneer trials are seen distinctly on aerial photographic maps.

With the aid of aerial photography, which has become very highly developed in the past few years, the airplane has become a most valuable surveying instrument. Cameras have been devised which not only portray large expanses, but which show with marvelous accuracy even slight details of relief. It is now possible to make in a few hours a survey for a pipe line or a new road across a mountain range which formerly would have required weeks of time by a party of surveyors. An important advantage of this method, too, is that the survey may be done without publicity and the consequent necessity to pay exhorbitant prices for rights of way.

Courtesy National Airlines, Inc.

Fig. 386. Locating submerged rocks, reefs, or sunken boats is the special mission of this plane

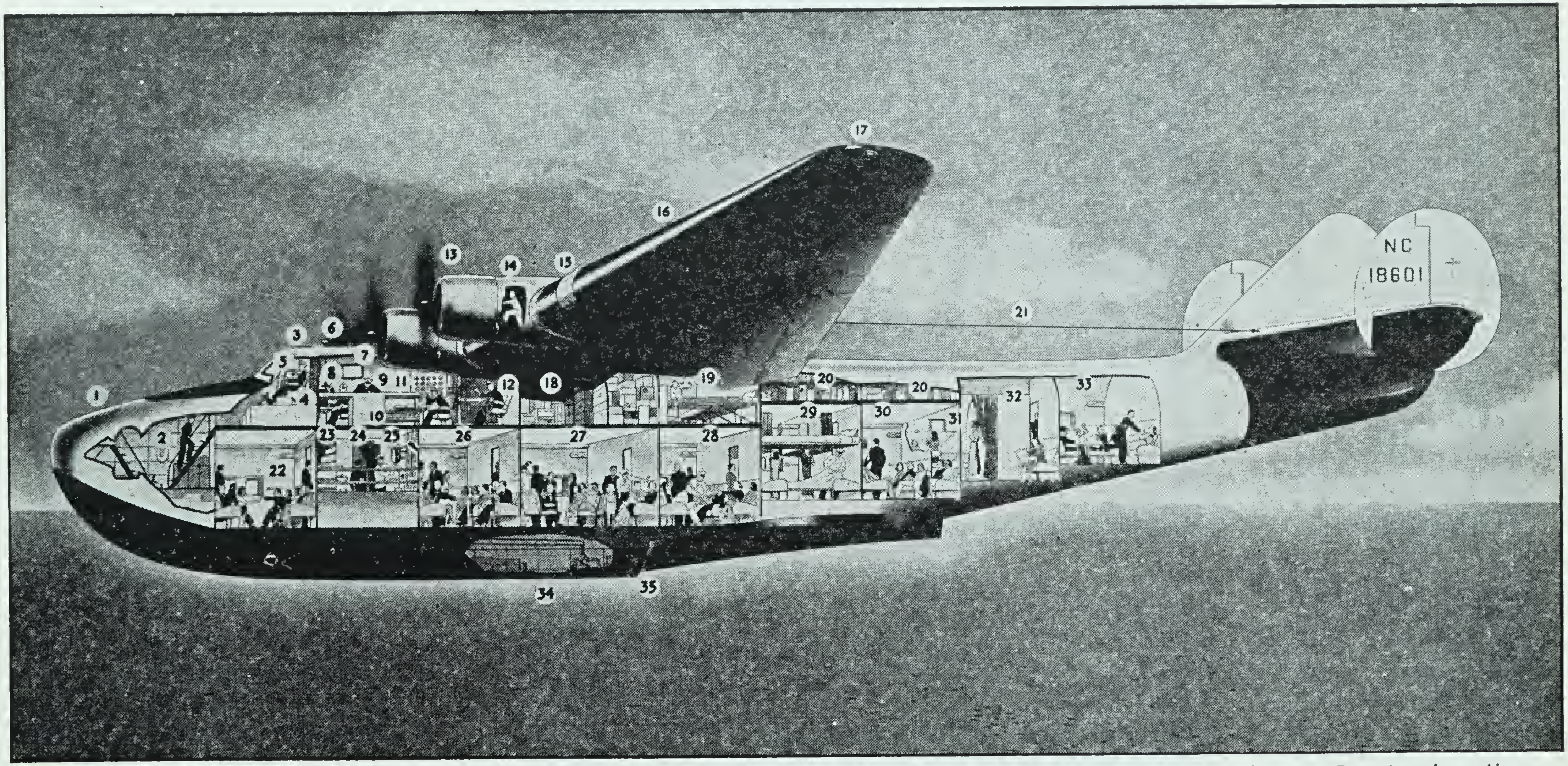
Similarly, many phases of geology may be profitably studied from the air. The kinds of rock structures may be identified; the direction and extent of certain formations may be determined. In May, 1942, a call was sent to geologists who had had experience in studying the earth from the air to give their aid to the Government in helping to locate suitable places for air bases, emergency landing fields, materials suitable for road building, features related to water supply, and to interpret relief maps and to construct other maps.

Airplanes have been used commercially and by sportsmen to locate schools of fish or packs of coyotes; they have been used to hunt men who have escaped from penal institutions; they have been employed by cowboys to locate and round up cattle. Shipwrecked sailors have in the airplane one of their hopes of rescue. Medicines and medical aid can be taken by air to the arctic regions or to the coast of Labrador, places which might be reached only after weeks of travel by dog team or boat. Forest fires are located from the air, and workers are given directions for reaching them. The lava flow from a volcano has been diverted from a village by a bomb dropped from a plane.

In a great flood in China, medicines and food were carried by air to stricken people, and others isolated by the waters were found and rescuers directed to them. After the recent New England hurricane the only means of communication among several large cities was by air.

The airplane is not an unmixed blessing. Constant dangers to the lives of persons and of plants are the communicable diseases, the plagues, and the insect pests which may be so easily transported from one part of the world to another. As the airplane, indeed, makes all the world akin, so does it subject the world to kindred maladies. To offset this negative value, however, the airplane offers the quick interchange of medical aid and of scientific knowledge. It makes possible researches of airborne germs and the like. It provides the means of spraying trees to kill caterpillars, of eliminating the boll weevil by dusting the cotton plants, of controlling malaria by spraying kerosene on swamps.

Innumerable other "air services" could be mentioned, such as the transportation of perishable goods, the planting of seeds—for example, over areas devastated by drought—sky-writing and other means of advertising; but by now it is clear that wherever the airplane is, there it will find things for its wings to do. And the airplane is everywhere.



Courtesy Pan American Airways

Fig. 387. Cutaway view of 74-passenger Trans-Pacific and Trans-Atlantic Flying Clipper Ship

Explanation of Fig. 387—(1) anchor hatch; (2) seaman's compartment; (3) bridge (where the flying controls of the liner are located); (4) first pilot; (5) second pilot; (6) radio direction-finder "loop"; (7) navigation compartment; (8) radio officer's post (9) chart room-navigator's post; (10) map case and marine library; drift-sight bombs, flares; navigational instruments; (11) engineering officer and mechanical engine and aircraft controls; (12) captain's office; (13) 1500 H. P. Wright "Cyclone" engines equipped with Hamilton constant-speed, automatic-adjusting propellers; (14) mechanic's wing station; (15) controllable landing lights; (16) wing spread 152 feet; (17) navigation lights; (18) main cargo hold which extends into wing; (19) crew's sleeping quarters; (20) luggage holds; (21) radio aerial; (22) first passenger compartment with accommodations for 10 persons; (23) spiral staircase to bridge; (24) men's retiring room; (25) galley in which two stewards can work simultaneously and where food can be prepared for 85 persons; (26) second passenger compartment with accommodations for 10 persons; (27) dining lounge with accommodations for 15 passengers; (28) third passenger compartment with accommodations for 10 persons; (29) fourth passenger compartment with accommodations for 10 persons, illustrating method of making up berths for conversion of airliner into ocean sleeper; (30) fifth passenger compartment for 10 persons; (31) ladies' dressing room; (32) sixth compartment; (33) private cabin suite; (34) fuel pumps for transferring fuel from sea-wings to wing tanks; (35) auxiliary hold.

In time of peace these giant ships flew from the United States to Europe and to Asia. They flew a regular passenger schedule to Hawaii and the Philippines. Wake Island was a fueling stop for the clippers. Residents of New York City and San Francisco enjoyed watching clippers arrive and depart.

In time of war the role of the clippers has been dramatic. They have helped refugees escape from Europe. They have flown diplomats to foreign countries. They have helped our armed forces. In the future even larger clippers will be built.

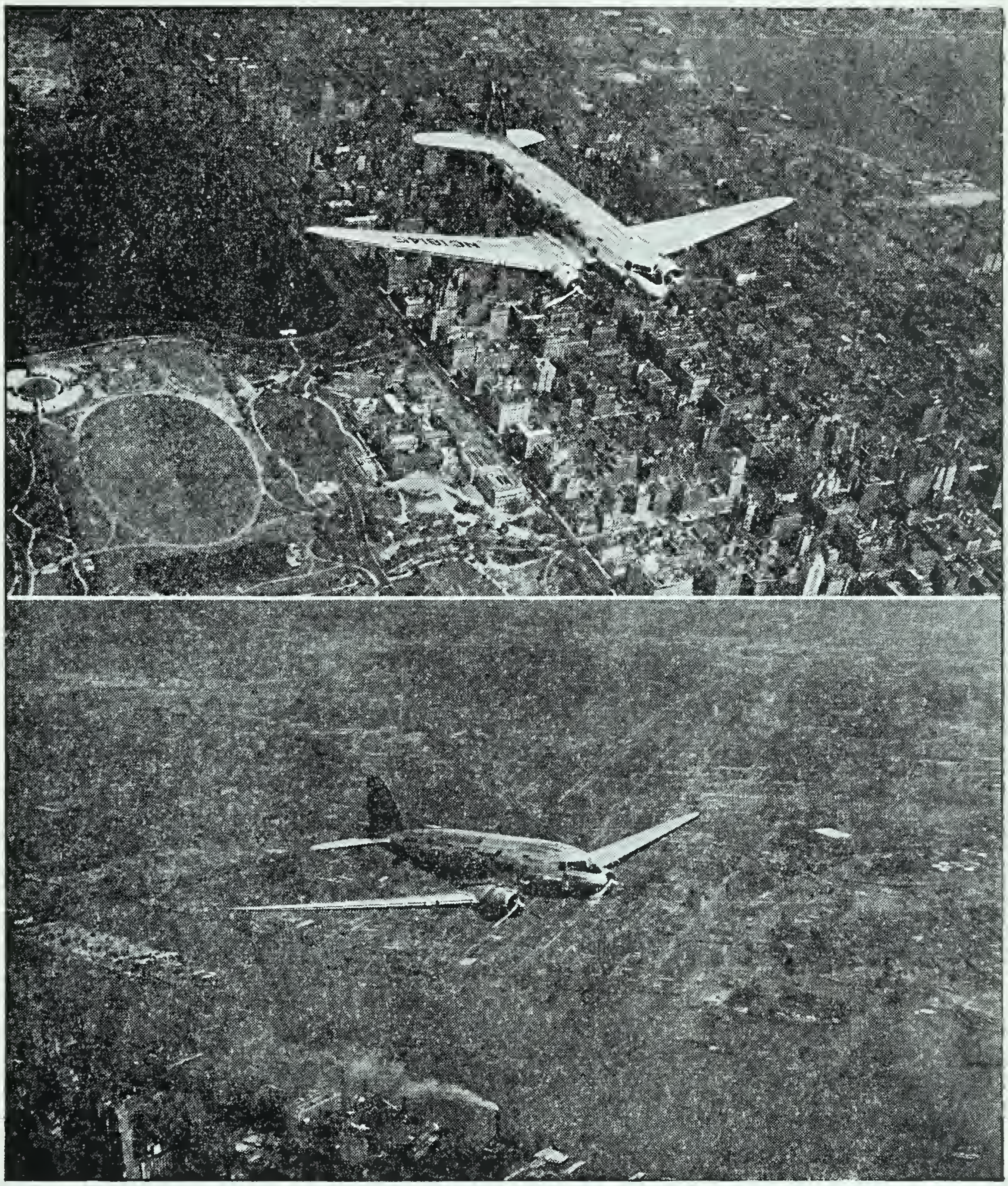
SOCIAL IMPLICATIONS OF THE AIRPLANE

The airplane is changing our way of life. Just as the automobile with its capacity for speed changed our way of living in terms of shifting populations, industrial planning, wider scope of entertainment, speed in emergencies, and personal growth, so is the airplane opening up another window on the world and quickening our prospects for an abundance of life.

Decentralization of population is bound to bring certain repercussions upon urbanization. Throughout the centuries, development of travel techniques along with geographical factors has been reflected in the growth and decline of cities. The navigation instruments of Prince Henry's school of navigation contributed to a shift of the bulk of commerce from the Mediterranean Sea to the Atlantic Ocean. This transfer and expansion of commerce caused a decline in the Italian cities in favor of those in The Netherlands, France, and England. Accompanying the growth in cities was a growth in banking interests, a higher valuation of property, and other social effects. Centuries later in the United States, the invention and mass production of the automobile permitted people to live in suburban communities outside cities in industrial areas, but at the same time it erased many of the small villages and hamlets which dotted the countryside in agricultural areas and tended to develop larger and fewer towns. The defense measures which at present restrict gasoline, tires, and even supplies tend to revive the "deserted villages." In a new age of speed it is possible that thriving little cities will relieve the overcrowded condition of metropolitan areas as well as break the monotony of the western plains.

The airplane foreshadows a readjustment in American cities to air transportation. It will make new demands for landing and storage facilities, which in turn will affect city planning and the manner of conducting business. More open spaces within central areas of cities will be in demand. Factories will need adjacent space for landing of cargo planes. In the same way, automobiles brought a need for parking space. Merchandise may be shipped by air directly from factory airports.

Civilian airplanes priced for the average man will have far-reaching effects upon man's social activities and the enriching of his life, providing he directs it that way. In 1938 the factories produced 3608 small planes. The production doubled in 1940. The war has cur-

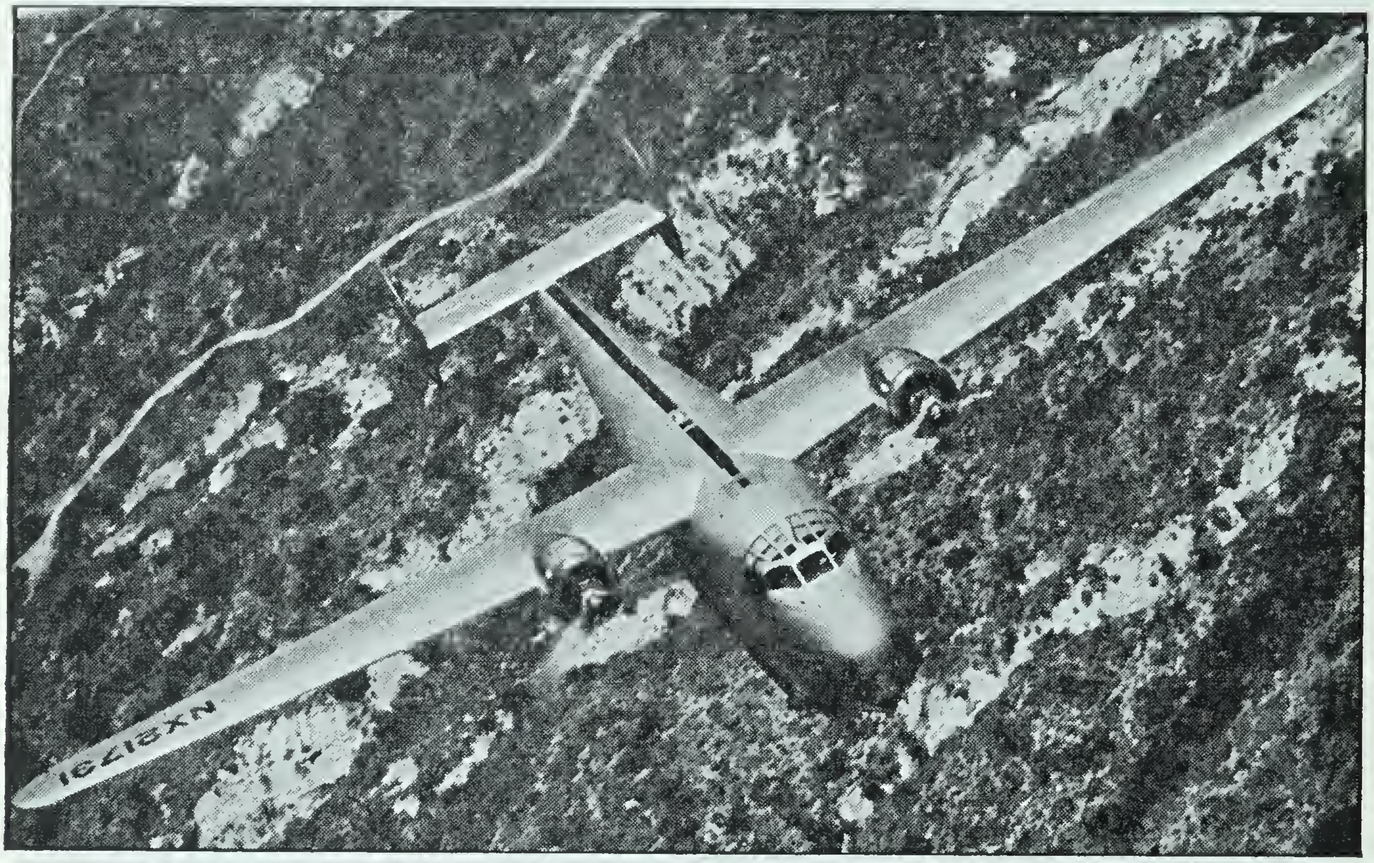


Courtesy Pratt & Whitney Aircraft

Fig. 388. The airplane promises decentralization of congested areas like the ones shown above.

tailed the production of small planes, but Fillmore Hyde declares in the article "A Plane in Every Garage" condensed from *Air Facts* by *Readers' Digest* that "What Mr. Public wants is a plane he can back out of his own garage, drive to a nearby take-off point, and quickly unfolding its wings, fly away. He wants a craft that will take off and land on either ground or water, come safely to earth anywhere in case of bad weather or mechanical trouble, and run along the highways at an automobile clip. And spokesmen for the industry say they can give it to him."

If such a prediction is near the truth, the social implications are almost limitless. It can mean the broadening of our cultural advantages. While one might fly to some city to enjoy a performance of the opera or to see a play, by the same means those attractions might be made available to the far-away town. With the World Series within a day's reach of the entire country, it is doubtful that the present amphitheater facilities would accommodate even a small fraction of the crowd. It is difficult to imagine the conduct of a Presidential campaign in the air age. With the entire country at once available, competition in industry, entertainment, education, and even religion might indeed be keen. These are only a few of the many social, political, and economic implications of living in an air age. They may be a long or a short time coming, but someone has wisely said, "If people take no care for the future, they will soon have to sorrow for the present."



Courtesy Consolidated Aircraft Corporation

Fig. 389. Plane of the future is this Consolidated Model 31, which was the first plane to be equipped with two 2000 horse-power motors. Commercially it is capable of carrying 52 passengers. The plane weighs 25 tons, has a 110-ft. wingspan. It is 73 feet long and 22 feet high. Speed and range of this craft have not been released but it greatly exceeds the PBY's in performance.

Exercise 12. Make a list of all the special services you can find which are rendered by airplanes.

Exercise 13. Report stories of actual cases in which some of the above services have been rendered. Example: How the airplane aided in the New England Hurricane of 1938. If a *Readers' Guide* is available consult it for references.

Exercise 14. Imagine yourself to be living in 1960 and to be making a journey by airplane from your present locality to some point several thousand miles away. Describe the trip including your preparation for the trip, the journey, and your arrival at your destination.

Exercise 15. Make a list of the ways in which the airplane is likely to affect your life from this time on. Consider food, clothing, recreation, entertainment, vocations, housing, location, health, and other general interests.

Problem 4. How is the airplane a vital factor in waging war?

Air Power in War

World War I introduced the combat plane. The year 1915 marks the beginning of its real development. At that time the British Scout biplane was the swiftest machine in the air, but the problem of arming it was unsolved. It is recorded that the first enemy plane was forced down through intimidation when a flier of a Bristol Scout opened fire with a revolver which rested on the edge of the cockpit. The development of the synchronized machine gun and the synchronizing gear and other improvements resulted in an outbreak of air fighting on a large scale. About the time the German Fokkers and Rolands, the British Bristol and Sopwith Scouts, and the French Moranes and Nieuports were taking part in aerial combat, the American Sturtevant Company put out the "United States Sturtevant Battle Airplane" which was the first to have fixed on the wings guns that would fire outside the airscrew disc. Many improvements and new designs in planes were introduced throughout the war, but the year 1917 seems to have produced the largest crop. One of the curious results of that harvest was the so-called "Flying Bedstead" put out by Voisin Brothers, the oldest airplane firm in the world. This machine was a two-seater gun-carrier with a 47 mm. gun, which is larger than those in common use today. It had a four-wheeled undercarriage, also an anticipation of modern machines. This plane is not remembered for any startling achievements.

1917 saw a marked development in speed and efficiency and a wider use of ground attack. Low-flying airplanes attacking troops on the ground proved to be one of the most devastating and demoralizing methods of warfare. It put the ground troops at the same disadvantage that the introduction of gunpowder did in the Middle Ages. Warfare had now gone into the third dimension. It meant that new formations of infantry must be adopted in order to make themselves least vulnerable to attack from above. The only obvious solution to such a dilemma was counter-aerial attack.

1918 saw the first use of the air force as a separate arm, cooperating with both army and navy and supplying some men and material. Night fighting was so successful in Britain in 1918 that German raids on British towns ceased. Many machines of greater speed and better motors were produced during the last year of the war. The first of the famous Junker airplanes appeared at that time. America produced a fighter called the Thomas-Morse M. B. with a 300 h.p. motor, a speed of 124 m.p.h. and a landing speed of 55 m.p.h. But it was never used in combat because the Armistice intervened. With the Armistice came a decline in the building of combat planes.

In 1920 there was held in the Rhön mountains of Germany a soaring-society meet which is sometimes spoken of as the real birth of the *Luftwaffe*. The development of soaring was Germany's way of evading the air-power restrictions of the Treaty of Versailles. In 1935 when Hitler announced his plans to build a great air force the foreigners laughed because they thought he had only a handful of trained pilots. But the facts show that Germany had a mighty corps of power pilots developed from a reservoir of several hundred thousand skilled soaring pilots. By the time of Munich, Germany had the mightiest air force in the history of the world.

It is obvious that the United Nations of the World War II have been slow in developing air power in terms of a long-range striking force. But for years aggressor nations have recognized the airplane as a versatile war machine, a sort of maid-of-all-work for armed services. Since Germany has exploited the use of the airplane to the full, many people in other nations, including the United States, have been inclined to think their countries had "missed the boat." Indeed there still may be some qualms. But Max Lerner, Professor of Political Science in Williams College, injects a good deal of hope for their side when he says, "There is nothing a dictatorship can do which a democracy cannot do better provided its leaders have the will and strength, and provided that its people are taught the facts."

Citizens of a democratic country can and must be alert. They have the opportunity to sit in the schoolrooms of the world and learn each day because they are free to learn. They can to a large degree discover the facts. They are free to discuss them; they are free to experiment; and they are free to have faith in the future. Under such circumstances of mass learning, free people will not only out-think the enemy, but they will out-act him. They will make up for lost time with up-to-the-minute people who are willing to stake all in order to preserve this great democratic experiment of ours.

The record of aerial activities of World War II may indicate to some that the democratic nations "missed the boat." But recent events tend to show that if they did "miss the boat" they are making a better one of their own!

The Airplane as a Weapon

The preceding paragraphs have dwelt rather generally upon the recognition and use of combat planes as a force in the last war, and with their decline during peace. A panoramic view of their participation in the present struggle as weapons of offense and defense may prove convincing if not enlightening. Long ago Napoleon Bonaparte planned his striking force in the form of the heaviest battalions. Germany's Field Marshal Goering has said, "Air power is striking power," and Germany has constantly stuck to the pattern of using the airplane as the spearhead of attack in World War II. The record thus far shows that no major offensive has succeeded against a force with superior air support. The influence of air power is becoming ever more important. Let the record speak for itself.

In 1939 most people anticipated a conflict, but everyone, with a few conspicuous exceptions, hoped the zero hour might be postponed. Berlin and Moscow had made a non-aggression agreement, so the coast was clear for the Nazi invasion of Poland. The opening note of the undeclared war was a bomb dropped on a small fishing village. An aerial attack was begun on Warsaw. For twenty days wholesale murder was rained from the skies. Warsaw was a shambles. On September 27 it surrendered.

And then after the deathly calm which caused many to think it a "phony war" came the invasion of Denmark and of Norway. Denmark, unable to resist, was occupied before noon of the first day. German planes flew on over the Norwegian capital. Warships appeared in the fjord leading to Oslo. There was a struggle with British sea power. But Germany, having the advantage of undeclared war and the coöperation of the Quisling element, also had an air force which was able to interfere drastically with England's attempts to reinforce the Norwegians.

May 10-20, 1940 brought the destruction of the Low Countries. At that time Germany had approximately 3,500,000 men, between 4,500 and 6,000 planes plus reserves, and twelve armored divisions. Allied forces did not compare with those by half. While the airplane was not the sole cause for Allied defeat, its part in bombing cities, bombing troops, bombing refugees, and landing troops behind enemy defenses cannot be ignored. Terrorization from the sky was a technique of "total war."

The British had withdrawn to the Channel ports when Belgium surrendered. There was no chance to rejoin the French army. Only evacuation by sea was left. You know the story of Dunkirk—how every tug and fishing boat, every power boat that could propel itself headed across the Channel from England to haul men off the beaches to the transports, merchantmen, and navy ships which could not reach the shallows. German planes had destroyed the port facilities. You recall how the evacuation was carried on under intense German bombardment from the air. But that power was challenged by the Royal Air Force which asserted a temporary superiority over the enemy. They made the evacuation possible.

The German land and air forces fell headlong into France. It is still too early to analyze France's incredible defeat.

Across the Channel rose the white cliffs of Dover. During the siege of France, England girded herself for battle as never before in her history. Germany controlled a line of air bases from northern Norway down the west coast of Europe to Spain. England was vulnerable. Then came the miracle of the R. A. F. (Royal Air Force). When at last the battle for Britain ended and England was not invaded, Prime Minister Churchill uttered those immortal words, "Never in the field of human conflict was so much owed by so many to so few."

In the battle for Britain, it was Germany's plan to use its air force as the opening wedge. It intended to drive British fighters out of the air, smash the fighter airdromes, and then bomb her south coast so an invading force could land. The battle of the Channel began on August 8, 1940, by dive-bomber attacks on shipping convoys. Dover, Portsmouth, and Portland were attacked, and in the course of time all parts of England and Wales and many parts of Scotland were bombed. A new phase of night raiding opened up on Coventry on November 14, 1940. For weeks incendiary and explosive bombs were concentrated on the midland industrial cities. For months this mounting inferno of destruction and slaughter only strengthened the people's will to resist, and they carried on. During these months of terror the R. A. F. with their Spitfires and Hurricane fighter planes made a splendid record against the German Messerschmitts and Heinkel fighters. Between August 8 and October 31, when daylight attacks ceased, Germany had lost 2,375 planes actually shot down. England admitted the loss of 375 pilots killed and 358 wounded during the same period of time. The total scores are not available, but England claimed the proportion of losses was fantastic. In the battle for Britain the airplane gave a remarkable account of itself as a weapon of defense as well as a weapon of offense. The type of machine and its manipulation obviously figured in the final outcome.

In 1941 the war turned eastward. The invasion of the Balkans was climaxed with the battle of Crete, where superior air power again told the story.

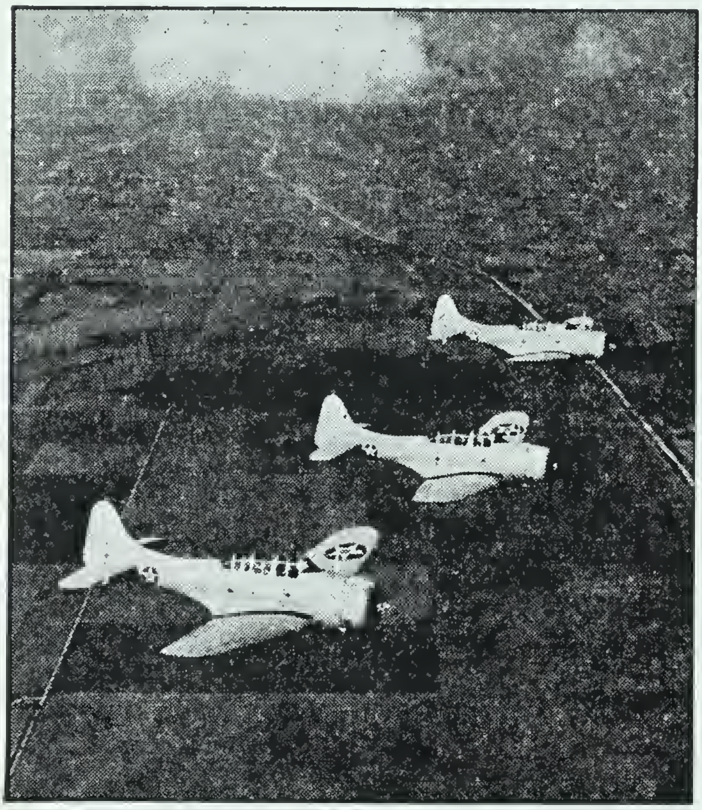
And then came Pearl Harbor on December 7, 1941—"A date that will live in infamy," said the President of the United States. We were at war with Japan. The story need not be related here. The ignoble attack was no complete test of American air power; it was, to our sorrow, a test of American alertness. It revealed a good deal of power stored up by our assailant, and it was undeniable evidence that aircraft could sink battleships. The importance of air power in the Pacific was clear.

Wake Island, over two thousand miles from Pearl Harbor and across the International Date Line, was attacked on December 8. For days 400 marines equipped with four fighting planes in flying condition and with limited shore batteries held out against a sizable force of destroyers and gun boats and bombers. Wake Island's "air force" was no match for bombers coming at the rate of thirty to forty a day, but it made a memorable record. The four planes made a total of ten attacks, sank one ship, damaged another, and bagged two bombers. The fliers share with the artillery men the glory of Wake

Island's heroic resistance. After fourteen days the Island was doomed to surrender.

Japan tightened its clutch on the South Pacific. England was dealt a powerful blow to her tradition as well as to her navy. Confidently, the battle cruiser *Repulse* and the battleship *Prince of Wales* steamed forth to seek contact with the enemy in the battle for Malaya. The fighting tops and decks bristled with anti-aircraft guns, but the ships had no air support. Down through the tropical skies came the dive bombers. From every direction came torpedo planes. The gunfire did not thwart them. Their losses must have been great, but their victory was greater, for they sank two of the finest ships in the British navy. It was costly proof that air power can be effective in independent action; that airplanes can be more than a match for the most powerfully armed battleships.

The lesson taught by the sinking of the *Repulse* and the *Prince of Wales* also spelled the doom of Singapore, whose safety rested largely on British sea power. There were a few Hurricanes at Singapore; but when the attack came, the British planes were hopelessly outnumbered. Land and sea forces combined with pulverizing aerial attacks to reduce the city. British sea power was not sufficient to maintain control of the proud city at the crossroads of the world. The Japanese chalked up another victory.



Courtesy Douglas Aircraft

Fig. 390. Dive bombers in flying formation

The toll in the Pacific was increasing. An epic of valor closed with the fall of Bataan and the subsequent surrender of Corregidor.

But the score was not wholly on the enemy's side. Late in January, 1942, an American raiding party sallied forth on an audacious thrust 2,000 miles from home port with a fleet of destroyers, cruisers, and aircraft carriers. A surprise attack was made upon the Marshall and the Gilbert Islands. The latter were British-owned but Japanese-occupied. First the bombers appeared over the islands.

Behind them came the torpedo planes and the warship guns. At the end of the raid the Navy chalked up a score of sixteen ships and submarines and forty-one planes. In the kill were a cruiser, a destroyer, two submarines, a converted aircraft carries, three tankers, and four freighters. The raid was an example of perfect timing and coördination of air and sea power in conducting an attack.

The democracies were learning their lesson well in the factories and at the front. In May, 1942, a great armada of Japanese ships set out to spear-head an all-out attack on Australia. To its great surprise, Japan received a hot reception and a crippling blow in the Coral Sea. The naval and air forces of the United nations destroyed the head of the spear. At least 19 Nipponese ships were sunk or damaged. For the United States aircraft carrier *Lexington,* it was "taps." But before she gave up to the sea, she sank one and probably two of the enemy's aircraft carriers. Not only do airplanes sink battleships, but they knock out carriers as well. Rear Admiral Sherman, captain of the *Lexington,* declared, "No defensive force can stop a determined offense by air."

Then came the greatest Japanese defeat in naval history. A striking force of four carriers, three battleships, many cruisers and destroyers with a supporting force of one carrier and more cruisers and destroyers set out for Midway and the Aleutian Islands. On June 3, 1942, an attack with fighters and bombers was made on America's Dutch Harbor. But the Navy kept its head cool and its powder dry. The Navy Patrol had sighted the Japanese fleet enroute to Midway and planned to give them a very warm welcome. When the assault was launched, planes of the Army, planes of the Navy, and planes of the Marines hit at the invaders with everything they had. The concentration of air strength of Midway dazed and bewildered the Japanese. Indeed, it did more. It routed their fleet and sent the remains scurrying home. The enemy losses were great. A possibly exaggerated report placed the number of Japanese vessels lost at fifty-five. While exact results are not available just now, it is clear that the destruction of Japanese carriers won the battle of Midway. The battle of Midway bears little resemblance to the great battle of Jutland in World War I. There was no naval combat between capital ships, for they were hundreds of miles apart. It was a battle of aircraft with naval supporting power. It proved that carrier planes have little chance against land-based planes.

While these accounts were beginning to square with the earlier scores of the war with Japan, England bombed the Channel ports, the Ruhr, the industrial cities of occupied France, of Italy, and of Germany. Cologne received a baptism of fire from the sky that dwarfed even the attack on Coventry. Essen, Hamburg, and Düsseldorf got the same. It appeared that Germany no longer had a monopoly on air superiority.

The record has spoken for itself. The first bombs dropped from a machine in the air were as revolutionizing as the use of gunpowder at the battle of Crecy or the use of iron-clad vessels in the battle of Hampton Roads.

Other War Services of the Airplane

Thus far we have dealt chiefly with the place of the airplane in military combat or contact with the enemy. There are important uses of planes auxiliary to the actual fighting. Planes capable of fighting or bombing are often called upon to perform duties of patrol, reconnaissance, transport, or scouting. These specific assignments do not often call for outright contact with the enemy except in an emergency. A few examples of such activity in World War II are worth attention.

On the eve of the war, Germany was far ahead of the United States and most European countries in the carriage of cargo. Germany's persistence in this respect can now be understood. Whole divisions of troops were transported by air from Denmark to Oslo when Norway was invaded. It marked the eclipse of sea power as self-sufficient service. It was cargo-plane service that saved the Nazi Rommel's army from destruction in the first siege of Libya and which contributed to his victory in the second.

Airmen's post-mortem of the loss of the Burma Road points out that trucks were compelled to cover 726 miles of winding road between Lashio and Chungking. By air the distance is 360 miles. The road's full capacity was 7,700 trucks capable of transporting 30,000 tons of material a month. Authorities declare that thirty-five air carriers only of types now in common use could have handled the cargo by flying three round trips a day.

One of the most spectacular incidents of the war thus far involved a United States Navy patrol bomber of the Catalina class. The German battleship *Bismarck* sank the British battlecruiser *Hood* near Iceland on May 24, 1941. The *Bismarck's* flight for safety was retarded by some crippling blows dealt by torpedo plane from the British carrier

Victorious. But the *Bismarck* survived the blows and managed to evade the enemy for thirty-two hours. When she was 500 miles west of Land's End she was discovered. Out from the clouds high above came a far-ranging Catalina. Signals soon told of her whereabouts. Like a trained bloodhound, the Catalina trailed the *Bismarck,* keeping her constantly in sight and keeping her enemies informed until the propitious moment. Torpedo planes from the *Ark Royal* swarmed for the kill. Surface boats were there to finish off the job. The *Bismarck,* like the *Hood,* found a resting place at the bottom of the sea. The ship would probably have reached safety had it not been for effective work of the long-range scouting plane.

The United States Congress recognized the importance of long range coupled with striking power when it scuttled some of its plans for battleships in favor of the aircraft carriers. The Congress further recognized the ability of air power to hop over both military and sea fronts and its power to strike where it will, when it introduced a bill authorizing more blimps. They have proved to be especially effective in spotting submarines. There has been some agitation in favor of building dirigibles to serve as troop carriers or for general transport service. Whether or not the twilight of sea power is at hand, the dawn of air power as a military service having an independent function has surely arrived.

World War II has demonstrated grimly and conclusively the overwhelming importance of a strong air force. The long-range bombers, the aircraft carriers, the modern designs of strength and speed, have given the isolationists their answer. Individuals who saw the foreshortening of the earth through airplane development could not fail to realize the insecurity of every nation's position when wars break out. The airplane has proved itself an effective weapon of war. It is up to this generation and the next and the next to see that it becomes a weapon of peace.

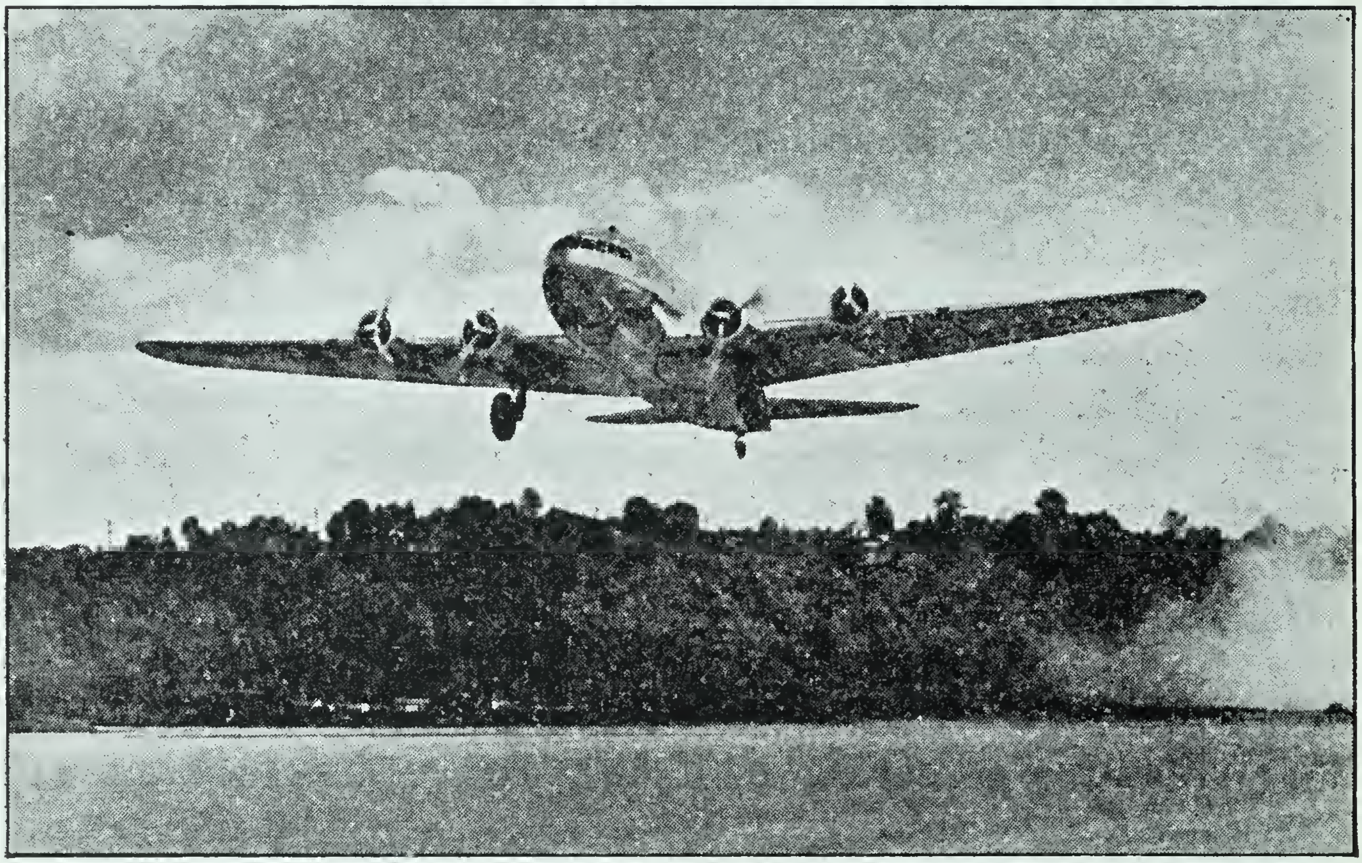
Exercise 16. In a notebook or scrapbook, paste newspaper clippings of accounts of aerial activity which you consider to be conclusive proof of the importance of air power in modern warfare.

Exercise 17. On a map of the world indicate the points of major conflicts in World War II. By color or design indicate Axis or United Nations victories. By symbols to represent land, air, and sea power, show how the two sides compared in each case.

Exercise 18. Plan a class discussion on this question: Is air power more important than sea power in modern war?

Exercise 19. Someone has said that the Pacific is where air power is destined to play the greatest role. Study the geography of the Pacific and decide wherein you do or do not agree with the statement.

Exercise 20. Compile information in notebook or chart form showing designs and explaining the function of bombing planes, torpedo planes, pursuit planes, patrol planes, and observation planes.



Courtesy Boeing Aircraft Company

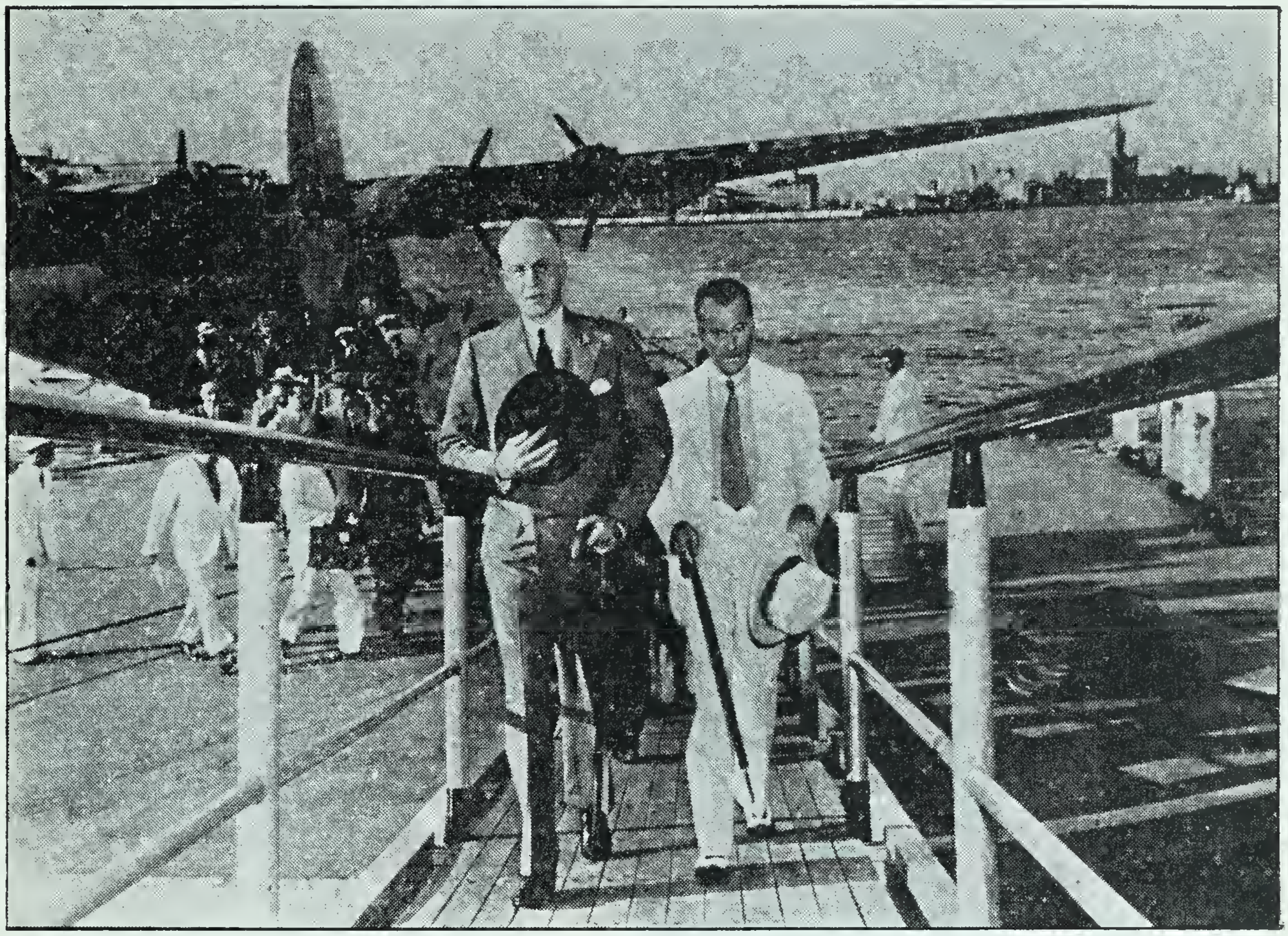
Fig. 391. "Strato-Clipper," a version of the Boeing Stratoliner used by Pan American Airways on the fast Latin America service. A fleet of these 250 mile-per-hour four-engine airliners speeds passengers and mail from the United States to our neighbors in South and Central America. Four 1100 horse-power Wright cyclones power these "altitude-conditioned," all-metal airliners. An efficient cabin supercharging system enables passengers and crew to enjoy low altitude pressure conditions even while flying high above surface storms at altitudes up to 20,000 feet. This ship weighs 22½ tons, spans 107 feet from wing tip to wing tip and is 74 feet long. The roomy cabin is 11½ feet in diameter. These ships recently have been put in government service.

Problem 5. How may the airplane be used to promote better relationships among nations?

PROMOTING THE GOOD NEIGHBOR POLICY

The airplane can be a force in making good neighbors of all people. Two centuries and a half ago William Penn made a treaty with the Indians which provided for "good neighborhood" between

Penn's colony and the natives as long "as the sun doth shine." While some of the neighbors of the United States have felt that the "colossus of the North" strayed a long way from that simple rule of life in the nineteenth and early twentieth centuries, they have been gratified by the adoption of the Good Neighbor Policy in recent years. In adopting such a policy the United States lived up to her traditions of tolerance, equality, and the right of government only by consent of the governed. In other words the United States recognized for her neighbors the right of life, liberty, and the pursuit of happiness.



Courtesy Pan American Airways

Fig. 392. Under-Secretary of State Sumner Welles arriving at Rio de Janeiro in the interest of the Good Neighbor Policy

As the American dream unfolded during the nation's adolescence, the ideals of tolerance and equality were woven into her social fabric. Men and women from every racial stock in the world came to America, faced the wilderness together, mingled their talents, developed common ideals regardless of their European heritage, and contributed their genius. They overcame language, religious, and political barriers. They proved the possibility of a community of nations.

Within the last few years the United States began to consider seriously her relations with Latin America. She realized that the people south of the Rio Grande were bound closely to Europe by ties of blood, culture, and of trade and to herself by the Isthmus of Panama and the Monroe Doctrine. While a combination of many conditions gave rise to the Good Neighbor Policy, the business of making it effective is largely a matter of facility for trade and passenger transport. International airlines are playing a large role in cementing hemispheric relations. Cargo planes are making possible the expansion of the market of perishable goods. Because of speed, flowers and delicate fruits can be carried thousands of miles by airplane without being damaged. Cargo planes can make a rapid adjustment of shortages and surpluses in many parts of the hemisphere. The airplane can go a long way toward making good neighbors by solving the dilemma of millions of people on low living standards who have been forced to dump their coffee or burn their wheat because of trade inequalities or poor transportation.

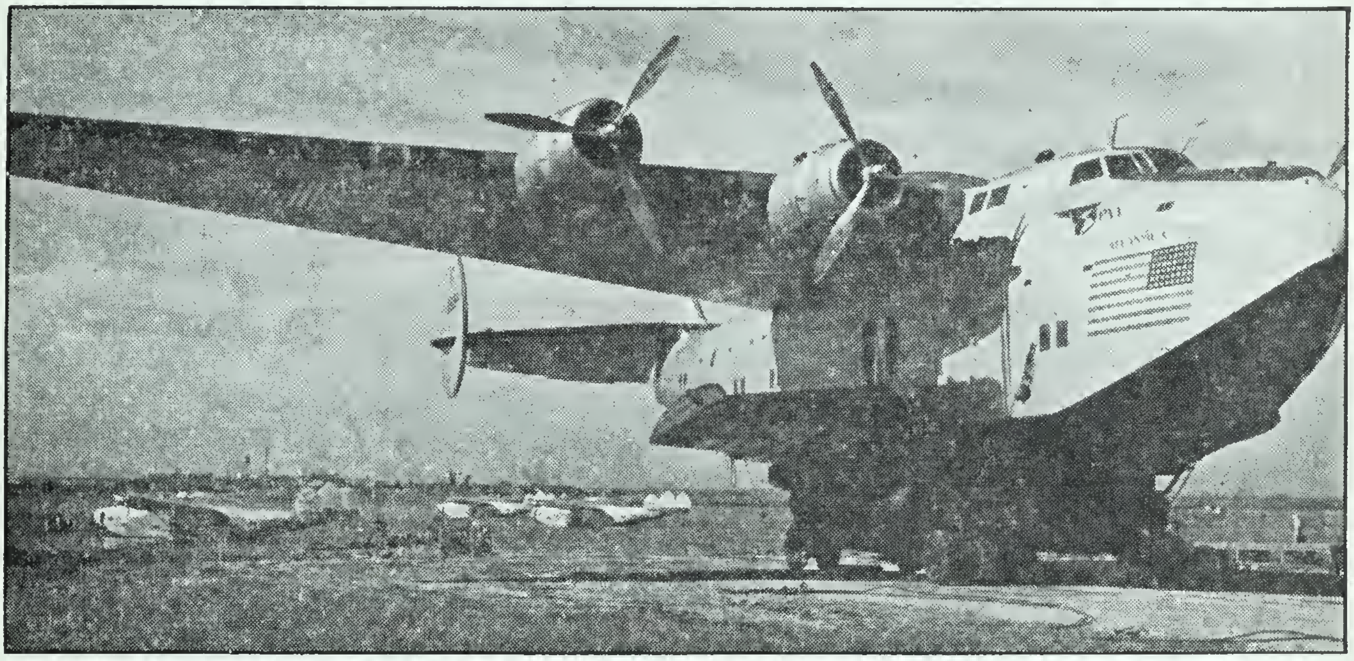
Courtesy Colonial Airlines, Inc.

Fig. 393. The Duke of Windsor visits America in the interest of hemispheric solidarity

The airplane is making possible a greater intermingling of the peoples north and south of the Rio Grande. It has been the carrier of many diplomats and representatives who have gone in the interest of peace and good will. Because people are intermingling with each other more they are understanding each other better. Through the channels of mutual interests neighborliness and opportunity the "American dream" is becoming a reality in the western hemisphere.

Recent international struggles and global war are convincing evidence that nations cannot confine themselves to hemispheres. They are irrevocably a part of a world. By the same tokens of equitable trade relations, a greater intermingling of peoples, and the recognition of everyone's right to life, liberty, and opportunity which characterizes a good neighborhood, the world can become a community of nations. The airplane through its capacity for speed, comfort, and safety is making neighbors of all people. It should be the goal of the twentieth century to achieve, through all of its facilities for knowing people and understanding their needs, the dream of human brotherhood.

The airplane is only an instrument created and controlled by man. It has ruthlessly demonstrated its capacity for war. Its capacity for peace remains to be seen. The respite between the wars has proved that a peace, to be effective, must be waged. It does not carry itself out automatically any more than any other law does. It must be enforced by constant vigil the same as other laws are. The airplane could be an effective means of viligance, provided the nations wish to make it so. The laws of many nations are made by representatives who meet regularly. When such laws outgrow their usefulness, they may be repealed in the same way. International law could be conducted on a similar basis, since the speed of the airplane makes it possible to hold regular and frequent meetings of representatives from all parts of the globe. The versatility of the airplane was discussed in **Problem 3.** When those services, including rescue work, stamping out of disease, and aid in all forms of emergencies, are translated into international good, then will the world move toward the goals of the United Nations.



Courtesy Pan American Airways

Fig. 394. A messenger of peace

The airplane need not be a "Frankenstein" which destroys its creator, but it may be a messenger of peace and good will so long as the motives of the people who control it are pure. The airplane is too powerful a weapon to be used freely by international outlaws. It can be a great builder of the democratic way of life if nations will nobly save, instead of meanly lose "this last best hope of earth."

Exercise 21. Prepare for a general class discussion on these questions:

a. Is air power more conducive to war than it is to peace?

b. Do you think each nation should be allowed to control the air above it, or should there be "freedom of the air" as well as freedom of the seas?

c. What precautions should man take to prevent the airplane becoming a kind of monster or "Frankenstein" which might result in the destruction of civilization?

Exercise 22. Trace the development of Pan-American relations. Show how rapid transportation has contributed to their development. In what ways might the airplane promote better future relationships among the nations of the western hemisphere?

Application Activities

1. Make a vocabulary list of words or phrases used in this unit which were new to you. Explain the meaning of each.

2. Make a collection of pictures of airplanes for a scrapbook. Arrange them in some orderly fashion such as according to type or according to date of model in order to show development, according to manufacturing companies, or in any order you choose providing you have some pattern of organization. Label carefully.

3. Make a *Who's Who* (miniature biographies) of people whose names are famous in the history and development of air transportation. Consider inventors, famous flyers, business executives, and government officials. Consult your text and your teacher for ideas.

4. Write a theme on one or more of the following topics:
   - *a.* Shall mankind become the slave or the master of the airplane?
   - *b.* How shall we prevent serious social dislocations in an air age?

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GLOSSARY

"A" power supply: a power-supply device providing heating current for the filament of a vacuum tube.

absolute temperature: The temperature of the Centigrade thermometer increased by 273° is increased on the Fahrenheit thermometer to 459°. This is due to the fact that absolute zero on the Centigrade scale is —273° and the corresponding absolute zero on the Fahrenheit scale is —459°.

acrobatics: evolutions voluntarily performed with an aircraft, other than those required for normal flight.

adiabatic: the word applied in the science of thermodynamics to a process during which no heat is communicated to or withdrawn from the body or system concerned. Adiabatic changes of atmospheric temperature are those that occur in consequence of compression or expansion accompanying an increase or a decrease of atmospheric pressure, and are usually associated with vertical motion of an air mass. Such changes are also described as dynamic heating or cooling.

advection: the process of transfer by horizontal motion, particularly applied to the transfer of heat by horizontal motion of the air. The transfer of heat from low to high latitudes is the most obvious example of advection.

advection fog: fog resulting from the transfer of warm, humid air over a cold surface, especially a cold ocean surface, or (comparatively rarely) from the transport of air that is relatively very cold over an ocean surface that is relatively very warm.

aerodynamics: the study of the motion of air and other gaseous fluids and of the forces acting on solids in motion relative to such fluids; mechanical effect of air in motion.

aeronautics: the science and art of flight.

aileron: a hinged or movable portion of an airplane wing, used to control the rolling of the airplane about the longitudinal axis. It is usually part of the trailing edge of a wing.

aircraft: a fixed-wing device designed to be supported by the air, either by buoyancy or by dynamic action.

airfoil: any surface, such as an airplane wing, aileron, or rudder, designed to obtain reaction from the air through which it moves.

airline: the great-circle route between two points.

air mass: a term applied by meteorologists to a large body of air within which the conditions of temperature and moisture in any horizontal plane are approximately the same.

airplane: a mechanically driven fixed-wing aircraft, heavier than air, which is supported by the dynamic reaction of the air against its wings.

dope: the liquid material applied to the fabric surfaces of airplanes to increase their strength, to produce tautness by shrinking, and to act as a filler for maintaining air-tightness.

pusher: an airplane with the propeller or propellers mounted to the rear of the main supporting surfaces.

tailless: an airplane in which the devices used to obtain stability and control are built into the wing.

airport: a tract of land or water which is adapted for the landing and take-off of aircraft.

airport of entry: an airport through air traffic may be cleared to or from a foreign country. Aircraft making an international flight must take-off from and land at such an airport, to comply with customs regulations.

airport traffic control: the control of local traffic in the vicinity of an airport by the airport management.

airscoop: a scoop or hood designed to catch (the air) and direct the flow of air against the engine heads or into the carburetor.

airspeed: the speed of aircraft relative to the air through which it is flying.

airspeed indicator: an instrument for indicating the air speed of an aircraft.

airway: an air route along which aids to air navigation, such as landing fields, beacon lights, radio direction-finding facilities, intermediate fields, etc., are maintained.

airway traffic control: the control of traffic on the airways, exercised by Federal personnel.

airworthiness: the quality of an aircraft denoting its fitness and safety for operation in the air under specified flying conditions.

altimeter: an instrument for registering the altitude of an aircraft, essentially an aneroid barometer with a scale which reads elevation in feet instead of pressure in inches or centimeters.

altimeter setting: the setting to be made to the barometric scale of an altimeter, such that, upon landing, the pointers of the instrument will indicate very closely the actual elevation of the airport above sea level.

altitude: the height of an airplane, usually expressed in feet above sea level; in celestial navigation, the angle of elevation of a celestial body above the horizon.

altitude, absolute: the height of an aircraft above the earth.

alternating current: a current the direction of which reverses at regularly recurring intervals, the algebraic average value being zero.

alto-stratus: a uniform layer of low, rather heavy, cloud.

amphibian: an airplane designed to rise from and alight on either land or water.

amplifier: a device for increasing the amplitude of electric current, voltage, or power.

anemometer: an instrument for measuring the speed of the wind.

angle—

drift: the horizontal angle between the longitudinal axis of an aircraft and its path relative to the ground.

dihedral: the angle between an imaginary line joining the wing tips and the plane of a wing.

flight-path: the angle between the flight path of the aircraft and the horizontal.

of attack: the acute angle between the wing chord and the effective direction of the air with respect to the wing.

of best glide: the acute angle between the horizontal and the most nearly horizontal path along which an airplane can descend steadily in still air when the propeller is producing no thrust.

of incidence: the acute angle between the chord of the wing and the longitudinal axis of the ship; built into the airplane, it does not depend upon the angle of attack.

antenna: a conductor or a system of conductors for radiating or receiving radio waves.

anti-cyclone: an area of high barometric pressure which is usually associated with clear and calm weather.

antitrades: the term applied to the winds which are observed at high elevations above the trade winds going in the opposite direction.

area—

horizontal tail: the effective combined area of the stabilizer and the elevators.

vertical tail: the area of the actual outline of the rudder and the fin projected in the vertical plane.

wing: the total area, including ailerons and the wing, is considered to extend without interruption through the fuselage.

atmosphere: the whole mass of air surrounding the earth.

attenuation: the reduction in power of a wave or a current with increasing distance from the source of transmission.

attitude of flight: inclination of the three principal axes of the airplane relative to the horizon.

autogiro: a type of rotor plane in which the wings are supplemented by a system of revolving blades hinged to a vertical shaft above the fuselage. The revolving blades rotate automatically after take-off.

automatic volume control: a self-acting device which maintains a constant output within relatively narrow limits while the input voltage varies over a wide range.

audio frequency: a frequency corresponding to a normally audible sound wave (upper limit approximately 30,000 cycles).

aviation: the operation of aircraft heavier than air.

aviator: the pilot of an aircraft heavier than air.

axes of an aircraft: consists of three fixed lines of reference: (1) the lateral axis, running through the center of gravity and parallel to a line drawn through the tips of the wings, (2) the longitudinal axis, running through the center of gravity from the nose to the tail, (3) the vertical axis, running through the center of gravity perpendicular to the other two.

"B" power supply: a power-supply device connected in the plate circuit of a vacuum tube.

bail out: to jump from a plane and use a parachute to reach earth.

bank: the rotation of a plane about its longitudinal axis; tilting a plane on its side.

barograph: an aneroid barometer which automatically records air pressure on chart fixed to a rotating drum.

barometer—

aneroid: an instrument indicating atmospheric pressure mechanically, by means of a resilient pressure chamber from which most of the air has been exhausted.

mercurial: an instrument indicating atmospheric pressure in terms of the height in inches or in millimeters of the column of mercury supported by it in an evacuated glass tube.

beacon—

airport: a light of high candlepower, located at an airport for the purpose of indicating its location.

airway: a light of high candlepower, located on or near an airway for the purpose of indicating its location.

beam: *see* equisignal zone.

Beaufort scale: a scale for estimating wind velocities by noting the visible effects of the wind.

biplane: an airplane with two main supporting surfaces placed one above the other, *i.e.*, a two-wing plane.

Buys Ballot's law: low-pressure areas exist to the right of an observer facing the wind in the northern hemisphere, while high-pressure areas exist to the left. The reverse is true in the southern hemisphere.

cabin: an enclosed space where pilot or passengers ride.

cable, control: the line of twisted wire cable leading from the control levers to the control surfaces.

calibration: the name ordinarily given to the process of ascertaining the values of the indicated readings of an instrument.

calm: absence of appreciable wind.

calms of Cancer, calms of Capricorn: the belts of high pressure lying north of the northeast trade winds and south of the southeast trade winds, respectively.

camber: the curvature of either surface of an airfoil with respect to its chord.

carburetor: apparatus on engine in which gasoline is vaporized and properly mixed with air forming a combustible fuel mixture.

carburetor heater: a device installed on the carburetor to insure proper mixture and to prevent icing due to cooling of moist air by vaporization of the gasoline.

cathode: the electrode from which the electron stream flows.

ceiling: height of lower level of a bank of clouds above the ground.

absolute: maximum altitude that a plane will reach under its own power.

service: the altitude at which the rate of climb drops below 100 feet per minute.

centigrade: a thermometric scale on which 0° denotes the temperature of melting ice, and 100° the temperature of boiling water, both under standard atmospheric pressure.

chandelle: an abrupt climbing turn to approximately a stall in which the speed of the airplane is used to obtain a higher rate of climb than would be possible in normal flight. The purpose of this maneuver is to gain altitude and at the same time change direction of flight.

chart, aeronautical: a small-scale representation of the region or district or country, its culture, relief, and the various aeronautical aids; designed with special consideration for the needs of air navigation.

chinook: a warm dry wind blowing down the eastern slopes of the Rocky Mountains over the adjacent plains in the United States and Canada, causing the rapid disappearance of snow in winter.

chord: a line from which the ordinates and angles of an airfoil are measured. It is usually the straight line tangent to the lower surface at two points or, in the case of double-cambered airfoil, the straight line between the leading and trailing edges of the wing.

chronometer: an accurate clock or watch, often with special conveniences for use in navigation.

circle, great: the intersection with the earth's surface of any plane passing through the center of the earth.

cirro-cumulus: small, white clouds, usually at a high altitude; mackerel sky.

cirro-stratus: a uniform layer of cloud at a high altitude.

cirrus: light, fleecy cloud, usually high. (*See* Figure 50.)

climate: the prevalent or characteristic weather conditions of any place or region.

climatology: the study of climate.

cloudburst: a sudden and extremely heavy downpour of rain; especially likely to occur in mountainous regions.

cloud cap or head: a cap-like cloud crowning a mountain summit or another cloud, especially a mass of cumulo-nimbus.

col: a neck of relatively low pressure between two anticyclones; also called a saddle back.

cold air mass: broadly speaking, an air mass that is cold relative to neighboring air masses. The term implies that the air mass originated in higher latitudes than those in which it now finds itself and that it is usually colder than the surface over which it is moving.

cold front: the discontinuity at the forward edge of an advancing cold air mass which is displacing warmer air in its path.

cold wave: a rapid and marked fall of temperature during the cold season of the year. The United States Weather Bureau applies this term to a fall of temperature in 24 hours equaling or exceeding a specified number of degrees and reaching a specified minimum temperature or lower, the specifications varying for different parts of the country and for different periods of the year.

compass—

card: a magnetic compass in which the magnets are attached to a pivoted card on which the directions are marked.

compensation: the correction of compass readings by inserting or adjusting small magnets incorporated in a magnetic compass for that purpose.

course: the true course plus or minus variation and deviation but without allowance for wind.

heading: the true course plus or minus variation and deviation and including allowance for wind; the direction by compass in which the airplane is pointed.

magnetic: an instrument indicating magnetic directions by means of a freely suspended magnetic needle; the primary means of indicating the heading or direction of flight of an aircraft.

rose: a circle, graduated in degrees from 0 to 360, printed on aeronautical charts as a reference to directions, true or magnetic.

testing platform: a platform designed for checking the directions indicated by the compass of an aircraft against known magnetic directions, and so determining the error, or deviation, of the compass.

cone, windsock: a tapered fabric sleeve pivoted on a standard to indicate the wind direction.

contact flying: flight of an aircraft in which the attitude of the aircraft and its flight path can at all times be determined by visual reference to the ground or water.

contour: an imaginary line formed by the intersection of a horizontal plane with the surface of the earth, all points on any given contour being at the same elevation with respect to sea level (or other chosen reference plane).

control—

surface: a movable airfoil designed to be moved by the pilot in order to change the attitude of the aircraft.

system: all parts having to do directly with the maneuverability of the plane.

controllability: the quality of an aircraft that determines the ease of operating its controls and the effectiveness of the controls in producing change in its attitude in flight.

controls: a general term applied to the means provided to enable the pilot to control the speed, direction of flight, attitude, and power of an aircraft.

convection: the upward or downward movement, mechanically or thermally produced, of a limited portion of the atmosphere.

convergence: the condition that exists when the distribution of winds within a given area is such that there is a net horizontal inflow of air into the area. The removal of the resulting excess is accomplished by an upward movement of air.

cowling: a removable covering over the engine.

crabbing a plane: to turn the head into the wind so that it will follow a correct flight path while flying in a cross wind.

crew: a group of men necessary for the landing and handling of an airship on the ground or in the air.

cross wind: wind crossing the line of flight.

culture: generally applied to the cities, railroads, highways, and other constructed features of the earth; often referred to as "the works of man."

cumulus: a cloud which takes a heaped-up form. (*See* Figure 53.)

cyclone: an area of low barometric pressure with winds rotating in a counter-clockwise direction in the northern hemisphere and a clock-wise direction in the southern hemisphere.

Civil Air Regulations: the regulations prescribed by the Civil Aeronautics Administration (C. A. A.) for the regulation and promotion of the many phases of aviation.

depression: a cyclonic area, or low.

deviation: the error of a magnetic compass due to magnetic influences in the structure and equipment of an aircraft, nearby iron-ore deposits, or a direct electric current.

deviation of the wind: the angle between the direction of the wind and the direction of the pressure gradient. (*Cf.* inclination of the wind.)

dew: atmospheric moisture condensed in liquid form upon objects cooler than the air, especially at night.

dewpoint: the temperature at which, under ordinary conditions, condensation begins in a cooling mass of air. It varies with the specific humidity.

diaphragm: a vibrating surface which produces sound vibrations.

direction—

course: the direction of the rhumb line, or the line of constant direction. As used in air navigation with the Lambert Projection, it is measured in a clockwise direction from true, magnetic, or compass north at the meridian nearest halfway between the starting point and destination.

heading: the direction in which the airplane is pointed, in contradistinction to its path over the ground.

wind: the true direction from which the wind blows.

directional gyro: a device using the gyroscope which after being set will indicate changes of heading rather accurately for a short period of time.

dive: a steep descent, with or without power, in which the air speed is greater than the maximum speed in horizontal flight.

disturbance: a local departure from the normal or average wind conditions of any part of the world, or, in other words, a feature of what is sometimes called the "secondary" circulation of the atmosphere, so distinguished from the general circulation. In everyday usage disturbance has come to be synonymous with *cyclone* and *depression.*

doldrums: the equatorial belt of calms or light variable winds, lying between the two trade-wind belts.

drag: the total force on the surface of the plane due to friction that retards the forward motion of the plane.

drift: the angle between the heading of an aircraft and its track, or flight path over the ground.

drift sight: an instrument for determining the angle of drift; often accomplished by observing the apparent motion of points on the earth's surface along a grid built into the instrument.

drizzle: precipitation consisting of numerous tiny droplets, originating from stratus clouds.

dry fog: a haze due to the presence of dust or smoke in the air.

eddy: a more or less fully developed circular motion in the atmosphere, constituting a local irregularity in a wind. All winds near the earth's surface contain eddies, which at any given place produce "gusts" and "lulls." Air containing numerous eddies is said to be "turbulent."

elevator: a movable auxiliary airfoil used to control the angle of attack, usually hinged to the stabilizer.

electron emission: the liberation of electrons from an electrode into the surrounding space. In a vacuum tube, it is the rate at which the electrons are emitted from the cathode. This ordinarily is measured as the current carried by the electrons under the influence of a voltage sufficient to draw away all the electrons.

engine, supercharged: an engine with a compressor for increasing the air or mixture charge taken into the cylinder beyond that inducted normally at the existing atmospheric pressure.

equator-terrestrial: an imaginary line formed by the intersection of the earth's surface and a plane perpendicular to the earth's axis at its middle point.

equi-signal zone: the zone within which signals from two adjacent quadrants of a radio range station may be heard with equal strength. A pilot flying along this equi-signal zone is commonly referred to as ***flying the beam.***

fading: diminishing of signal strength because of increasing distance from a radio station, or because of other radio phenomena.

Fahrenheit: a thermometric scale on which 32° denotes the temperature of melting ice, and 212° the temperature of boiling water, both under standard atmospheric pressure.

fall-wind: a wind blowing down a mountain side; any wind having a strong downward component. Fall-winds include the Foehn, mistral, bora, etc.

fidelity: the degree to which a system, or a portion of a system, accurately reproduces at its output the signal which is impressed upon it.

fin: a fixed or adjustable airfoil attached to the tail of an aircraft to provide directional stability.

fishtail: a term describing the motion made when the tail of an airplane is swung from side to side to reduce speed in approaching the ground for a landing.

fix: a definite position of an aircraft, determined by the intersection of two or more bearings or lines of position, or by other means.

flap: a hinged or pivoted auxiliary airfoil attached at the trailing edge of the wing, used to increase lift at reduced air speed.

flutter: an oscillation set up by a disturbance in any part of an aircraft.

fog: a cloud at the earth's surface. Fog consists of numerous droplets of water, which are so small that they cannot readily be distinguished by the naked eye. In ordinary speech the term "fog" generally implies an obscurity of the atmosphere sufficiently great to interfere with marine and aerial navigation.

forces: the agents acting on a plane, such as drag, lift, thrust, gravity.

frequency: the number of cycles per second.

front: a surface of discontinuity between two side-by-side currents of air possessing different densities, or, more simply, the boundary between two different air masses.

frost: atmospheric moisture deposited upon terrestrial objects in the form of ice crystals; also called hoarfrost.

fuel system: all parts of the plane having to do directly with the consumption of gasoline.

fuselage: the body to which the wings and tail unit of an airplane are attached, usually streamlined.

gale: wind with an hourly velocity exceeding some specified value (25-75 miles per hour). In American practice a wind of or exceeding force eight on the Beaufort scale is counted a gale.

glide: a normal controlled descent without power.

gnomonic: a chart projection on which all great circles are exactly represented by straight lines.

gradient wind: a wind of the velocity which is necessary to balance the pressure gradient. The direction of the gradient wind is along the isobars, and the velocity is so adjusted that there is equilibrium between the force pressing the air toward the region of low pressure and the centrifugal action to which the moving air is subject in consequence of its motion.

Greenwich: the location of the principal British observatory, near London. In most countries, longitude is reckoned east or west from the meridian through this observatory.

ground loop: an uncontrollable violent turn of an airplane while taxiing or during the landing or take-off run.

ground school: school for pilots in theory of flight, navigation, meteorology, etc.

ground speed: the speed of an aircraft with reference to the surface of the earth (note wind velocity, air speed, and heading influence in this).

gust: a sudden brief increase in the force of the wind. Most winds near the earth's surface display alternate gusts and lulls.

hail: balls or irregular lumps of ice, often of considerable size, having a complex structure; large hailstones generally have a center, surrounded by layers of ice, which may be alternately clear and cloudy. Hail falls almost exclusively in connection with thunderstorms. (*Cf.* sleet.)

hangar: a shelter for housing airplanes.

haze: a lack of transparency in the atmosphere caused by the presence of dust or of salt particles left by evaporated ocean spray. At a certain distance, depending on the density of the haze, all details of landscape and color disappear.

high: an area of high barometric pressure; an anticyclone.

horizon—

artificial: in celestial navigation, the horizon obtained by means of a spirit level incorporated in the optical system of a bubble sextant; also a gyroscopic instrument designed to show the attitude of the plane about both vertical and lateral axes, sometimes called the gyro horizon.

natural: the line where earth and sky seem to meet.

horsepower: unit by which rate of work is measured—one horsepower is 550 footpounds of work in one second, or the equivalent of lifting 550 pounds one foot in one second.

hot wave: a period of abnormally high temperatures. It has sometimes been defined, in the United States, as a period of three or four consecutive days during each of which the maximum temperature is 90° F. or over.

humidity: the degree to which the air is charged with water vapor. This may be expressed in several ways: **Absolute humidity** expresses the weight of water vapor per unit volume of air. **Relative humidity** is the ratio of the actual vapor pressure to the vapor pressure corresponding to saturation at the prevailing temperature, or simply the percentage of saturation. **Specific humidity** expresses the mass of water vapor contained in a unit mass of moist air, and is the only true conservative air mass property of the three.

hurricane: a tropical cyclone, especially one of the West Indian region. (A cyclone originating in this region and passing northward into the Temperate Zone is often called a ***West Indian hurricane,*** even after it has assumed the character of an extratropical cyclone, and if sufficiently severe justifies the display of *hurricane warnings* at ports of the United States.) ***Hurricane*** is also the designation of the highest wind force on the Beaufort scale.

hygrometer: an instrument for measuring the humidity of the air.

Immelman turn, normal: a maneuver made by completing the first half of a normal loop; from the inverted position at the top of the loop, half-rolling the airplane to the level position, thus obtaining a 180° change in direction simultaneously with a gain in altitude.

inclination of the wind: the angle which the wind direction makes with the direction of the isobar at the place of observation. Over the ocean the angle is usually between 20° and 30°. (*Cf.* deviation of the wind.)

indirectly heated cathode: a cathode of a thermionic tube, in which heat is supplied from a source other than the cathode itself.

insolation: solar radiation, as received by the earth or other planets; also, the rate of delivery of the same, per unit of horizontal surface.

instrument flying: the art of controlling an aircraft solely by the use of instruments; sometimes called ***blind flying.***

inversion: an abbreviation for "inversion of the usual order of temperature changes in the atmosphere." The temperature of the air is ordinarily observed to become lower with increasing height, but occasionally the reverse is the case, and when the temperature increases with height there is said to be an inversion.

isobar: a line on a chart or diagram drawn through places or points having the same barometric pressure, referred to sea level. (Isobars are customarily drawn on weather charts to show the horizontal distribution of atmospheric pressure reduced to sea level or the pressure at some specified altitude.)

isogonic line: an imaginary line on the surface of the earth at all points on which the magnetic variation is the same.

isotherm: a line on a chart or diagram drawn through places or points having equal temperatures.

kilocycle: when used as a unit of frequency, 1,000 cycles per second.

knot: a velocity of one nautical mile per hour (1853.25 meters per hour).

Lambert projection: the chart projection used as a base for aeronautical charts of the Coast and Geodetic Survey. Straight lines on this projection closely approximate great circles, and distances may be measured with a high degree of accuracy.

land and sea breezes: the breezes that, on certain coasts and under certain conditions, blow from the land by night and from the water by day.

landing: the act of terminating flight in which the aircraft is made to descend, lose flying speed, establish contact with the ground or water, and finally come to rest on three points.

area: that portion of the field available for the take-off and landing of aircraft.

gear: the understructure which supports the weight of an aircraft when in contact with the land or water and which usually contains a mechanism for reducing the shock of landing. Also called *undercarriage.*

pancake: a landing in which the leveling-off process is carried out several feet above the ground, as a result of which the airplane settles rapidly on a steep flight path in a normal attitude.

three-point: the art of terminating flight, landing with the wheels and tail skid or wheel touching the ground simultaneously.

lapse rate: the rate of decrease of temperature in the atmosphere with height.

latitude: distance north or south of the equator, measured in degrees, minutes, and seconds of arc.

light—

anchor: one or more white lights carried on an aircraft to indicate its position at night while at anchor.

blinker: a light giving more than 20 flashes per minute.

boundary: one of the white or clear lights designed to indicate the limits of the landing area of an airport or landing field.

identification: a group of lights, clear and colored, carried on the rear part of an airplane for identification at night.

position: a group of lights—red, green, and clear—used aboard an aircraft to indicate its position and direction of motion.

lightning: a disruptive electrical discharge in the atmosphere or, generally, the flash attending such a discharge.

line squall: a more or less continuous line of squalls and thunderstorms marking the position of an advancing cold front.

link trainer: a model plane having closed cabin and no windows, in which pilots simulate air navigation and instrument flying.

load factor, in flight maneuvers: the ratio of the aerodynamic load imposed upon the lifting surfaces in a specified maneuver to that imposed in normal level flight.

load—

full: weight empty, plus useful load; also called gross weight.

useful: the crew and passengers, oil and fuel, ballast other than emergency, or cargo, and portable equipment.

loading, wing: the gross weight of an airplane divided by the wing area.

longitude: the arc along the equator between the meridian passing through a place and (usually) the meridian of Greenwich; measured in degree, minutes, and second of arc.

loop: a maneuver executed in such a manner that the airplane starting from normal flight passes successively through a climb, inverted flight, dive, and back to normal flight.

low: an area of low barometric pressure, with its attendant system of winds; also called a barometric depression or cyclone.

maneuver: to operate an aircraft in a skillful manner.

maneuverability: that quality in an aircraft which determines the rate at which its attitude and direction of flight can be changed.

marine climate: a type of climate characteristic of the ocean and oceanic islands. Its most prominent feature is equability of temperature.

megacycle: when used as a unit of frequency, a million cycles per second.

mercator: the chart projection commonly used for nautical charts. On this projection the rhumb line is represented by a straight line; great circles (radio bearings are great circles) are represented by curved lines. Due to the rapidly expanding scale, distances must be measured with the scale for the middle latitude between the two points in question.

meridian, true or geographic: any of the great circles passing through the geographic poles of the earth.

meteorology: the science of the atmosphere.

mile—

nautical: the ordinary unit of 6080.20 feet (1853.25 meters) for measuring distances at sea. For practical purposes a minute of latitude may be considered equivalent to a nautical mile. It is approximately equal to 1.15 statute miles.

statute: the ordinary unit of 5,280 feet for measuring distances on land. It is approximately equal to 0.87 nautical miles.

millibar: a unit of barometric pressure, 1,000 millibars being equal to 29.53 inches of mercury; conversely, 1 inch of mercury is equal to 33.86 millibars.

mirage: an apparent displacement or distortion of observed objects by abnormal atmospheric refraction. Sometimes the images of objects are inverted, magnified, multiplied, raised, or brought nearer to the eye than the object. Refraction layers in the atmosphere often assume the appearance of fog.

mist: a very thin fog, in which the horizontal visibility is greater than 1 kilometer, or approximately 1100 yards. (This is the definition laid down by the International Meteorological Organization.) In North America the word is often used synonymously with drizzle or fine rain.

monoplane: an airplane with but one main supporting surface, sometimes divided into two parts by the fuselage; a one-wing plane.

monsoon: a wind that reverses its direction with the season, blowing more or less steadily from the interior of a continent toward the sea in winter, and in the opposite direction in the summer.

multiple courses: a number of narrow equi-signal zones resulting from the breaking up of a radio range course by mountainous topography or other causes.

nacelle: an enclosed shelter for personnel or for a power plant; usually shorter than a fuselage, and without a tail unit.

navigation—

celestial: the determination of position by means of sextant observations of the celestial bodies, together with the exact time of observation.

dead reckoning: determination of position from knowledge of direction, velocity, and elapsed time from a known point.

piloting: directing an airplane with respect to visible landmarks.

radio: the determination of position by means of observed radio bearings.

normal: the average value which in the course of years any meteorological element is found to have on a specified date or during a specified month or other portion of the year, or during the year as a whole; also used as an adjective in such expressions as "normal temperature." The normal serves as a standard with which values occurring in a particular year may be compared in order to determine the departure from the normal.

north—

magnetic: the direction indicated at any place on the earth's surface by a magnetized needle undisturbed by any local magnetic attraction.

true: the direction of the north geographic pole.

nose: forward part of plane.

noseheavy: the condition of an airplane in which the nose tends to sink when the longitudinal control is released in any given attitude of normal flight.

nose-over: an expression referring to the accidental turning over of an airplane on its nose when landing.

nose-up: to elevate the nose of an airplane in flight.

nucleus: a particle upon which condensation of water vapor occurs in the free atmosphere in the form of a water drop or an ice crystal.

occluded front: a line along which a cold front overtakes a warm front. This cold front marks the position of the front at the surface of the earth.

occlusion: the term used to denote the process whereby the air in the warm sector of a cyclone is forced from the surface to higher levels. The process is accompanied by an increase in the intensity of the cyclone.

oleo gear: a type of hydraulic shock-absorbing device used in landing gear to ease the shock effect in landing.

oscillatory circuit: a circuit containing inductance and capacitance, such that a voltage impulse will produce a current which periodically reverses.

over-all length: the distance from the extreme front to the extreme rear of an aircraft, including the propeller and the tail unit.

over-the-top flying: flight of aircraft made above an overcast, usually a cloud formation.

overshoot: to fly beyond a designated mark or area, such as a landing field, while attempting to land.

parachute: an umbrella-like device used to retard the descent of a falling body by offering resistance to its motion through the air.

harness: a combination of straps, buckles, and fastenings used to attach a parachute to the wearer.

pack: a parachute and its container.

rigger: a person who packs, repairs, and inspects parachutes.

parallel: the intersection of the earth's surface with a plane parallel to the equator.

pilot balloon: a small free balloon the drift of which, as observed from the ground, indicates the movements of the air aloft.

pitch: plane's up or down movement about its lateral axis.

pitch of a propeller (effective pitch): the distance an aircraft advances along its flight path for one revolution of the propeller.

plate: a common name for the principal anode in a vacuum tube.

polar continental air: the term used to describe any air mass that originates over land or frozen ocean areas in the polar regions. Polar continental air is characterized by low temperatures, low specific humidity, and a high degree of vertical stability.

polar front: the surface of discontinuity separating an air mass of polar origin from one of tropical origin.

polar maritime air: the term used to describe any air mass that originally came from the polar regions but has since been modified by reason of its passage over a relatively warm ocean surface. Polar maritime air is characterized by moderately low surface temperatures, moderately high surface specific humidity, and a considerable degree of vertical instability.

pole—

celestial: the point on the celestial sphere intersected by the extension of the earth's axis.

magnetic: a point on the earth where a freely suspended magnet, free from local disturbances, would point vertically. The north magnetic pole is located at about latitude 71° north, longitude 96° west, the south magnetic pole at about latitude 73° south, longitude 156° east.

power amplification (an amplifier): the ratio of the alternating current power produced in the output circuit to the alternating current power supplied to the input circuit.

precipitation: the collective name for deposits of atmospheric moisture in liquid and solid form, including rain, snow, hail, dew, hoarfrost, etc.

pressure: an expression, current in meteorological literature, for atmospheric pressure, or barometric pressure; also force per unit area.

pressure gradient: the decrease in barometric pressure per unit horizontal distance in the direction in which the pressure decreases most rapidly.

prevailing westerlies: the belts of winds lying on the poleward sides of the subtropical high-pressure belts.

propeller: any device for propelling a craft through a fluid, such as water or air; especially a device having blades which, when mounted on a power-driven shaft, produce a thrust by their action on water or air.

adjustable: a propeller whose blades are so attached to the hub that the pitch may be changed while the propeller is at rest.

automatic: a propeller whose blades are attached to a mechanism that automatically sets them at their correct pitch for various flight conditions.

controllable: a propeller whose blades are so mounted that the pitch may be changed while the propeller is rotating.

geared: a propeller driven through gearing, generally at some speed other than the engine speed.

root: that part of the blade near the hub.

thrust: the component of the total air force on the propeller which is parallel to the direction of line of flight.

psychrometer: an instrument for measuring atmospheric humidity, consisting usually of a dry-bulb thermometer and a wet-bulb thermometer. The former is an ordinary mercurial thermometer. The latter has its bulb covered with muslin or other fabric, which is either permanently wet or is wetted before use. In some psychrometers there is only one thermometer, reading being taken both before and after moistening the bulb. In the aspiration psychrometer the air is drawn past the bulb by a revolving fan.

pull-out: the change of position of plane from a dive to horizontal flight.

pull-up: a maneuver in which the airplane is forced into a short climb, usually from approximately level flight.

radiation fog: fog characteristically resulting from the loss of heat of air near the surface of the ground on calm, clear nights.

radio—

altimeter: a device for measuring the height of an aircraft above the surface of the earth (not above sea level), by means of reflected radio waves.

channel: a band of frequencies or wave lengths of a width sufficient to permit of its use for radio communication. The width of a channel depends upon the type of transmission.

compass: a device employing a fixed loop antenna and visual indicator; used chiefly for "homing" flight (flight directly toward or away from a radio station).

direction finder, automatic: similar to the ordinary radio direction finder, except that rotation of the loop is automatic and the indicator needle continuously indicates the bearing of the station.

receiver: a device for converting radio waves into perceptible signals.

transmitter: a device for producing radio-frequency power, with means for producing a signal.

radius of action: the distance of time an aircraft, without using up the entire gasoline supply, may safely fly toward its destination before turning back to the starting point or to some alternate airport.

reciprocal: any given direction (whether course, bearing, or heading) plus or minus 180°.

rectifier: a device having an asymmetrical conduction characteristic which is used for the conversion of an alternating current into a pulsating current. Such devices include vacuum-tube rectifiers, gas rectifiers, oxide rectifiers, electrolytic rectifiers, etc.

rectifying (correcting): the process of removing from the compass heading observed in flight the errors due to deviation, variation, and wind.

relief: the inequalities in elevation of the surface of the earth; represented on the aeronautical charts by contours and gradient tint.

resonance frequency (of a reactive circuit): the frequency at which the supply current and supply voltage of the circuit are in phase.

rheostat: a resistor which is provided with means for readily adjusting its resistance.

rhumb line: a line on the surface of the earth, crossing all meridians at a constant angle.

rip cord: the cord, together with the handle and fastening pins, which, when pulled, releases a parachute from its container.

roll: a maneuver principally conducted by means of the ailerons.

rudder: a hinged or movable auxiliary airfoil on the rear of an aircraft, the function of which is to impress a yawing movement or turn.

rudder bar: the foot bar by means of which the control cables leading to the rudder are operated.

saturation: the condition that exists in the atmosphere when the water vapor present is equal to the maximum amount of vapor possible at the prevailing temperature.

secondary: a small area of low pressure on the border of a large or "primary" one. The secondary may develop into a vigorous cyclone while the primary center disappears.

sextant: an instrument used in celestial navigation for determining the altitude of a celestial body above the horizon.

shower: a fall of rain, of short duration but often of considerable intensity and usually consisting of relatively large drops. Also a similar fall of snow, sleet, or hail. Showers characteristically fall from isolated clouds separated from one another by clear spaces. They occur typically in air masses that possess a high degree of instability.

side bands: the bands of frequencies, one on either side of the carrier frequency, produced by the process of modulation, or changing from one key to the other.

sideslipping: motion of an aircraft relative to the air, in which the lateral axis is inclined and the airplane has a velocity component along the lateral axis. When it occurs in connection with a turn, it is the opposite of skidding.

signal: the intelligence, message, or effect conveyed in communication.

skidding: sliding sidewise away from the center of curvature when turning. It is caused by banking insufficiently, and is the opposite of **sideslipping.**

skin friction: the clinging action or resistance force on a surface.

sleet: frozen or partly frozen rain; frozen raindrops in the form of particles of clear ice.

slipstream: the current of air driven astern by a propeller.

slot: the nozzle-shaped passage through a wing whose primary object is to improve the air flow conditions at high angles of attack. It is usually near the leading edge.

snow: precipitation in the form of small ice crystals, falling either separately or in loosely coherent clusters (snowflakes).

soar: to fly without engine power and without loss of altitude, as does a glider in ascending air current.

sounding balloon: a free, unmanned balloon carrying a set of self-registering meteorological instruments.

source region: an extensive area of the earth's surface characterized by essentially uniform surface conditions and so placed in respect to the general atmospheric circulation that air masses may remain over it long enough to acquire definite characteristic properties. Examples of source regions are the ice-covered polar regions and the broad expanses of uniformly warm tropical oceans.

spar: one of the main lateral members of the wing, usually of wood or tubular steel.

speed—

flat: a spin in which the longitudinal axis is less than 45° from the horizontal.

ground: the horizontal progress of an aircraft relative to the ground.

normal: a spin which is continued by reason of the voluntary position of the control surfaces, recovery from which can be effected within two turns by neutralizing or reversing all the controls. Sometimes called **controlled spin.**

spin: a maneuver in which an airplane descends in a spiral motion moving forward and downward, the tail describing larger arcs than the nose.

stalling: the speed of an airplane in steady flight at its maximum coefficient of lift; the minimum speed at which a plane can remain under control in normal flight.

take-off: the air speed at which an airplane becomes entirely air-borne.

spinner: a conical-shaped cap which is fitted on the propeller hub and revolves with the propeller.

spiral: a maneuver in which an airplane descends in a corkscrew fashion, the angle of attack being within the normal range of flight angles.

squall: a sudden storm of brief duration, closely akin to a thunderstorm but not necessarily attended by thunder and lightning; a sudden brief blast of wind, of longer duration than a gust.

stability: a state in which the vertical distribution of temperature is such that an air particle will resist displacement from its level. In the case of unsaturated air the lapse rate for stability will be less than the dry adiabatic lapse rate, in that of saturated air less than the saturated, adiabatic lapse rate.

stabilizer: any airfoil whose primary function is to increase the stability of an aircraft. It usually refers to the fixed horizontal tail surface of an airplane, as distinguished from the fixed vertical surface or fin.

stall: the condition where forward motion or flying speed is retarded to the extent that the plane noses down; also defined as the condition of an airplane which is operating at an angle of attack greater than the angle of attack of maximum lift.

stick (control): the vertical lever by means of which the longitudinal and lateral control surfaces of an airplane are operated. The elevators are operated by forward and backward movement of the stick; the ailerons, by a side-to-side movement.

storm: a marked disturbance in the normal state of the atmosphere. The term has various applications, according to the context. It is most often applied to a disturbance in which strong wind is the most prominent characteristic, and sometimes specifically to a wind of force 11 on the Beaufort scale. It is also used for other types of disturbance, including thunderstorms, rainstorms, snowstorms, hailstorms, dust storms, sand storms, magnetic storms, etc.

strato-cumulus: large balls or rolls of cloud which often cover the whole sky. (*See* Figure 52.)

stratosphere: the upper region or external layer of the atmosphere, in which the temperature is practically constant in a vertical direction. The stratosphere is free from clouds (except occasional dust clouds) and from strong vertical air currents—in other words, active convection. The height of its base (*see* **tropopause**) varies in regular fashion with latitude and with the seasons over the earth as a whole, and fluctuates irregularly from day to day over any particular place.

stratus: a fleecy cloud formed in long horizontal layers.

streamlining: shaping of a part so as to create the least disturbance of air passing around it.

strut: a compression member of a truss frame (a brace).

subsidence: the word used to denote a slow downward motion of the air over a large area. Subsidence accompanies divergence in the horizontal motion of the lower layers of the atmosphere.

supercharger: a pump for supplying the engine with a greater weight of air or mixture than would normally be inducted at the prevailing atmospheric pressure.

tachometer: an instrument that measures in revolutions per minute (rpm) the rate at which the crankshaft of an engine turns.

tail, airplane: the rear part of an airplane, usually consisting of a group of stabilizing planes, or fins, to which are attached certain controlling surfaces such as elevators and rudders.

tail skid: a skid for supporting the tail of an airplane on the ground.

tailheavy: the condition of an airplane in which the tail tends to sink when the longitudinal control is released in any given attitude of normal flight.

take-off: the act of beginning flight in which an airplane is accelerated from a state of rest to that of normal flight. In a more restricted sense it is the moment when the contact of the plane with the ground ceases.

teletype: a system of communications by automatic typewriters, operated by wire or by radio. Extensively used by the Civil Aeronautics Administration in transmitting weather data and other flight information.

thermograph: a self-registering thermometer.

thermometer: an instrument for measuring temperature; in meteorology, generally the temperature of the air. Maximum and minimum thermometers indicate, respectively, the highest and lowest temperatures occurring between the times of setting the instrument. A wet-bulb thermometer is used in measuring humidity. (*See* **psychrometer.**)

thunder: the sound produced by air rushing together after a flash of lightning.

thunderstorm: a storm attended by thunder and lightning. Thunderstorms are local disturbances, often occurring as episodes of cyclones, and, in common with squalls, are marked by abrupt variations in pressure, temperature, and wind.

time—

civil: time measured by the rotation of the earth with respect to the sun, a definite moment, hour, or day.

standard: the civil time adopted as standard within a zone approximately 15° of longitude in width.

tornado: a violent whirling motion in the atmosphere, attended by a pendulous, more or less funnel-shaped cloud; in West Africa, a common term for a violent thundersquall.

torque: the twisting or rotatory force on the plane caused by the revolutions of the engine; generally overcome by giving one wing a slightly greater lift.

torque stand: a stand on which engine torque is measured.

total emission: the value of the current carried by electrons emitted from a cathode under the influence of a voltage such as will draw away all the electrons emitted.

tower, airport control: the communication center through which pilots receive traffic instructions from the local airport management and from the Federal airway traffic control center, and to which they report the required flight information.

trade winds: two belts of winds, one on either side of the equatorial calm in which the winds blow almost constantly from easterly direction.

transition zone: the relatively narrow region occupied by a front wherein the meteorological properties exhibit large variations over a short distance and possess values intermediate between those characteristic of the air masses on either side of the zone.

tropopause: the point in the atmosphere at which the fall of temperature with increasing height abruptly ceases. This point marks the base of the stratosphere. Over most of the earth it is located, on the average, at elevations of between 10 and 15 kilometers (6 and 9 miles) above sea level. Its normal level over the polar regions is somewhat below 10 kilometers and over the equator somewhat above 15 kilometers.

troposphere: the lower region of the atmosphere from the ground to the tropopause, in which the average condition is typified by a more or less regular decrease of temperature with increasing altitude.

trough: an elongated area of low barometric pressure.

turbulence: irregular motion of the atmosphere produced when air flows over a comparatively uneven surface, such as the surface of the earth, or when two currents of air flow past or over each other in different directions or at different speeds. The existence of turbulence in the atmosphere is made apparent by the character of the trail of smoke from a ship's funnel and by gusts and lulls in the wind.

turn indicator: an instrument for indicating the rate of turn about the vertical axis, usually combined with a "ball bank indicator" to show whether or not the controls are properly coördinated in exacting a turn; that is, whether or not the correct angle or bank is used.

V-shaped depression: a trough of low barometric pressure bounded, on the weather map, by V-shaped isobars.

vane: a device that shows which way the wind blows; also called **weather vane** or **wind vane.**

variation, magnetic: the angle between true north and magnetic north at any given place.

veer: of the wind, to shift in a clockwise direction; opposite of **back.** In scientific practice this definition now applies to both hemispheres.

viscosity (oil): a measure of the flowing properties of oil.

visibility: the greatest distance toward the horizon at which conspicuous objects can be seen and identified.

voltage amplification: the ratio of the alternating voltage produced at the output terminals of an amplifier to the alternating voltage impressed at the input terminals.

wave: a propagated disturbance, usually periodic, a single cycle of such a disturbance, or a periodic variation as represented by a graph.

wave length: the distance traveled in one period or cycle by a periodic disturbance.

warm air mass: broadly speaking, an air mass that is warm relative to neighboring air masses. The term implies that the air mass originated in latitudes lower than those in which it now finds itself and that it is, therefore, warmer than the surface over which it is moving.

warm front: the discontinuity at the forward edge of an advancing current of relatively warm air which is displacing a retreating colder air mass.

warm sector: the area bounded by the cold and warm fronts of a cyclone.

wash: the disturbance in the air produced by the passage of an airfoil. Also called the **wake** in the general case for any solid body.

waterspout: a tornado-like cloud occurring over a body of water.

wedge: a wedge-shaped area of high barometric pressure as shown on a weather chart, synonymous with **ridge**; applied to an air mass whose advancing forward portion, from a three-dimensional standpoint, is shaped like a wedge.

weight-fixed airship: the weight of the machinery and all equipment and parts that are fixed in position and nonconsumable. Liquids in the cooling systems of the engines are included.

weight, gross (airplane): the total weight of an airplane when fully loaded.

wheel, tail: a wheel used to support the tail of an airplane when on the ground. It may be steerable or nonsteerable, fixed or swiveling.

wind: moving air, especially a mass of air having a common direction of motion. The term is generally limited to air moving horizontally, or nearly so; vertical streams of air are usually called **currents.**

angle: the angle between the true course (or the heading, as the case may be) and the direction from which the wind is blowing; measured from the true course (or the heading) toward the right or left, from 0° to 180°.

tee: a large T-shaped weather vane located on a landing field or on the top of an adjacent structure to indicate the direction of the wind. It may have the form of an airplane and may be illuminated for night landings. Also called **landing tee.**

tunnel: an apparatus producing an artificial wind or air stream, in which objects are placed for investigating the air flow about them and the aerodynamic forces exerted on them.

wing: a general term applied to the airfoil, or one of the airfoils, designed to develop a major part of the lift of a heavier-than-air craft.

heavy: the condition of an airplane whose right or left wing tends to sink when the lateral control is released in any given attitude of normal flight.

over: a maneuver in which the airplane is put into a climbing turn until nearly stalled, at which point the nose is allowed to fall while continuing the turn, then returned to normal flight from the ensuing dive or glide in a direction approximately 180° from that at the start of the evolution.

profile: the outline of a wing section.

rib: a chord-wise member of the wing structure of an airplane, used to give the wing section its form and to transmit the load from the fabric to the spars.

section: a cross-section of a wing.

wire, antidrag (airplane): a brace wire.

zenith: the point on the celestial sphere directly over the head of the observer.

zoom: to climb for a short time at an angle greater than the normal climbing angle, the airplane being carried upward at the expense of kinetic energy or forward movement.

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